The Application of LCA Impact Assessment to Environmental Performance Indices: A Comparative Study.

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Submitted for the degree of
Doctor of Philosophy (Ph.D.)

October 1997

This work is dedicated to three very special people

Lisa Eales

A free spirit who I admire and love

Gabriël Daalmans

My grandfather, who passed away on 25th September 1995.

Michael Fitzsimmons

My godson, who greeted this world on 31st March 1996.

ABSTRACT

A wide variety of assessment techniques are presently available to quantify the environmental performance of an organisation. They are predominantly site- or area-specific, making them sensitive to differences in the environmental capacity of an area, and they exclude a number of global impacts. A more generic level-plane assessment tool, which quantifies the environmental burden, may therefore be needed to make a valid comparison between organisations. Furthermore, the generic process data used in these assessment tools, to inform policy decisions on a material or product, does not recognise the potential variation in burden of a sector.

This thesis develops a corporate level-plane assessment tool using the techniques available from Life Cycle Assessment. This generic tool, the Total Environmental Potency Index (TEPI), is then compared with the Environment Agency's Integrated Environmental Index (IEI), to assess the significance of site location on compliance based site-specific indices like the IEI. The two indices are compared using real-world emission data from seven industrial collaborators in five sectors. Two of these, paper manufacture and power generation, are used to assess the potential variability among processes within the same sector. The potential use of the indices is also determined by examining the accessibility to the required data at each of the participating companies.

The results show that site location significantly affects the IEI and that the TEPI can provide a useful generic impact assessment tool to compare sites from different locations or sectors. The burdens from processes within the same sector were highly variable, suggesting that process-specific data will be important if valid policy decisions are to be made in the future. The TEPI and its categories can provide a standard format for aggregating and presenting the required emission data in a way that protects its commercial sensitivity. Although the accessibility to this data was low to moderate, the potential for deriving emission data using mass balance studies was high, with a large amount of accessible input data available.

The implications of these results for the use of internal and external impact assessment techniques within an organisation are discussed. A framework is provided to guide the use of process data and impact assessment techniques in the wide range of assessments made by organisations to manage and report on their environmental performance. Finally, the experiences gained from using the IEI and TEPI are used to make recommendations for their improvement, and further development by research.

Key-words.
Integrated Pollution Control, IPC, Best Practicable Environmental Option, BPEO, Environmental Performance Indicators, EPI, Life Cycle Assessment, LCA, Impact Assessment, Integrated Environmental Index, IEI.

ACKNOWLEDGEMENTS

I would like to thank all those people and organisations that have contributed to this project and to the final thesis. In particular I would like to thank:

(i) The Department of Environmental Science at the University of Stirling, for their financial and practical support over the last three years. Special thanks to the project supervisors, Dr. Carol Salt, Dr. Peter Burbridge and Dr. Ian Simpson, for their guidance and comments, and to the department's staff for making me feel welcome during my stay in Scotland.

(ii) The staff at environmental consultants Aspinwall & Company, for their practical and moral support, as well as financial assistance and contacts which allowed me to reach a wide range of companies and kept me in touch with the real world. I would especially like to thank Dr. David Davies for his belief in the initial project as well as support and contacts, my three mentors, Ms Lucy Candlin, Dr. Simon Pollard and Dr. Gus Carroll for their contacts, comments and enthusiasm, and Dr. Owen Harrop for his help on the air dispersion modelling part of the project. You kept the Flying Dutchman in the air! ☺.

(iii) The management and staff of the participating companies, who freely gave data (once I had signed my soul away), and access to their operations and resources. Thank you for making me feel welcome and putting up with all my questions and demands. A special thank you to Dr. Charles Whittaker, Dr. Graham Hamilton, Dr. Chris Marden, Dr. Morag Hart, Mr. Paul Musgrove, Dr. David Christie and Dr. Paul Anderson for their support, and comments on the company chapters. You gave the Flying Dutchman a place to land! ☺.

(iv) To all those organisations that provided additional data and help for the project. Special thanks are due to: the distribution companies who gave of their time to provide specific data for the sites concerned; the Scottish Environment Protection Agency who provided guidance and data for the modelling of releases to water; Dr. David Bowers of the Centre for Ocean Sciences at Bangor for his advise on modelling releases to estuaries; the Institute for Applied Environmental Economics in the Netherlands, for free data on air emissions from sea transport operations; and Dr. Jarvis of the University of St. Andrews for providing contour data on one of the estuaries.

(v) All my friends and family, in Stirling, the UK and abroad, for their support over the last three years. Thanks to all those in Stirling for sharing the daily ups and downs and for many a good night out (Sarah for all the good food, Rob for all those pints, and Caroline for being an endless source of enthusiasm). Thanks also to the "lads and lasses" in the North for making the effort despite the long distances that divided us (Andy, Andrew, Matt & Kate, Neil & Glenis, Nick, Kevin & Lorraine, and Reet). Also thank you to the Southerners, Dominic & Linda Osborne, Anna Jamison, and Robert & Sharon Fitzsimmons for moral support and good food. Further afield, thanks to the Yanks (Megan, Jenn, Amanda & Tiffany {through the wonders of E-mail}), Angelique and Robert {NL}, and Si^2. Last but not least, to my mother in the Netherlands for worrying too much.

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DECLARATION

I hereby verify that the contents of this thesis are based on the results of my own work and have not been included in any other thesis. Where used, other sources are acknowledged in the text.

Ronald Daalmans

Ronald J G Daalmans
Stirling, October 1997

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INTRODUCTION

Environmental Indices & Sustainability

The last twenty-five years have seen an increased awareness of the pressures that human activity is placing on the physical and ecological environment. More recently this has been followed up by efforts to reduce these pressures and move towards a more sustainable society. The traditional definition of sustainable in this context has been to meet the needs of the present without compromising the ability of future generations to meet their needs. This ability has primarily been measured using economic instruments. However, some physical measurements have also been carried out.

One of the first studies to examine whether anthropogenic pressures could be sustained, called the Limits to Growth, was commissioned by the Club of Rome (Meadows et al. 1972). The report concluded that, based on present trends, the limits to growth on the planet would be reached within the following 100 years. During the 1980s the study was backed up the Brundtland Report (WCED 1987), which stated many similar conclusions. In response, both the UK and EEC/EC increased the amount of environmental legislation imposed on industry and society.

Despite this legislation, and within only twenty years of the Limits to Growth study, its sequel - Beyond the Limits - showed that many resources and pollutants had already been taken past their physical limits (Meadows et al. 1992). The urgency of the problems identified was confirmed at that time by a high-level intergovernmental conference, the Rio Earth Summit. The agreements reached at this conference have since gone a long way towards making other parts of society start to think about the issues of sustainability and sustainable development.

Following the conference initiatives have been set up by national governments, local authorities and companies to steer them towards a more sustainable existence. In order to achieve a sustainable level these organisations need to measure their environmental performance or burden. It is this area of work that forms the arena for this thesis. Within that arena the definitions for what is sustainable have been slightly changed from the traditional version. The measures for this thesis will exclude those socio-economic values inherent in traditional economic instruments, and concentrate solely on the physical limits and interaction of the environment. Sustainability might then be described as:

(i) Operation of a process or activity within the physical limits of the local environment to produce or absorb materials so as to ensure its long-term health and existence.

(ii) Meeting the needs of the present as far as is physically possible within or up to the physical limits of the environment to produce or absorb materials without compromising the ability of future generations to do no less.

Context.

The quantification of an organisation or nation's sustainability is presently under development, using a wide variety of techniques. Most of these presently use a range of indicators, which describe the use of particular resources or releases of pollutants. In some cases these pressures may then be compared to a measure of the assimilative or carrying capacity of the ecosystem affected. Other approaches have attempted to bring these indicators together into a single measure or index. However, due to the complexity of the earth's environmental systems, and the limited knowledge available on how they work and interact, present indices use different techniques and assumptions to achieve this. Some also include the social and economic dimensions of sustainable development in the index. These value based weightings may be included in addition to the physical indices or used to as means of relating one indicator to another in the absence of known physical relationships. The use of these techniques to report externally on the environmental performance of an organisation, and internally to manage its processes and develop its products, are discussed in Chapters 1 and 2 respectively.

One of the main problems identified in these chapters is the use of both site-specific compliance based indices as well as generic level plane assessment tools. Furthermore, the basis for the use of the two approaches has not been defined. This interchangeable use of the two index types has the potential to give significantly disparate results when comparing organisations or products.

The use of site-specific indices introduces a site dependent variable into the assessment, which does not occur within the generic approaches. Given the wide range of environments and river catchment areas present even within the UK, the assimilative or carrying capacity of one area is likely to vary significantly from another. This combined with the number of other operations exerting a pressure on that area, will affect the amount of capacity remaining and thus the outcome of any compliance based index. Many of the site-specific indices also exclude a number of global environmental problems covered by the generic approaches. Comparison or aggregation of data from companies operating in different locations would, therefore, be invalid as the burden which can be absorbed at each site will differ. Consequently, there may be a need for a more generic approach for use at a higher level. At present, however, both techniques are used at a site-specific and corporate level as indicators of environmental performance.

An additional problem within the product assessment tools available is the use of generic sector data as a substitute for supplier specific data when making material use comparisons for product improvement. Given the potential variability in burden from processes within the same sector this may require the provision of emission or burden data at a company rather than sector level. Some form of standard environmental accounting system may be needed to collect and present this data.

Research Problem.

The primary aim of this project is to develop a physical generic level plane assessment tool and establish whether such a tool is needed in order to make valid high-level assessments. A generic index, called the Total Environmental Potency Index (TEPI), is derived from the Life Cycle Assessment techniques described in Chapter 2. This index quantifies the environmental burden of a set of emissions on a generic ecological environment, excluding social or economic factors. As these factors do not represent the true physical relationships and limits to the environmental systems being quantified, they have been left out of this study. Other indices are being developed assess the socio-economic effects of life-cycle studies (see Section 2.2.2). The TEPI is then compared to a site-specific index to ascertain whether site location significantly affects the results obtained from the latter. The Environment Agency's Integrated Environmental Index (IEI) will be used as a site-specific assessment tool.

The indices are applied to a set of seven industrial collaborators who have provided emission data, or for which emissions have been estimated using mass balance studies. To establish whether the two indices can be used interchangeably the IEI and TEPI will be compared graphically and tested for independence. This will be supported with a sensitivity test of the two indices to assess whether they both respond in the same way to changes in emissions. Disparities between the indices in either assessment mean that a distinction must be made between site-specific and generic assessments, together with a framework to guide their appropriate use.

The second part of the study aims to establish whether the process-specific and generic emission data can be used interchangeably within the product LCAs from which TEPI has been derived. Two sets of two companies will be used to assess this by looking at the potential difference between processes in the same sector and establishing the variability within the processes themselves. Where this variability is high an environmental accounting tool may be needed to collect and present this information to clients and stakeholders.

The potential use of the TEPI as such a tool will be examined within the UK electricity market. The significance of the environmental burden of electricity use at each of the participating companies will be assessed, together with the effect on this burden of changing from the UK average generation mix to Scottish Power or Scottish Hydro-Electric. Finally, potential use of both the IEI and TEPI at the participants will be assessed by assessing the accessibility to the data required to calculate them.

The rationale behind the study, together with the basis of the two indices used, the participating companies and the methods used to assess the results are described in Chapter 3. Process descriptions of the companies taking part, together with the derivation of emissions, modelling of site-specific releases, and derivation of the IEI and TEPI are given in Chapters 4 to 10. Comparison of the indices, together with the data quality results are given in Chapter 11. The implications of these results on the use of impact assessment techniques, both inside and outside an organisation, and the research needs required to develop the indices further are discussed in Chapter 12.

CHAPTER ONE

Environmental Performance Measures

From Continent To Company

1.1 Introduction.

This chapter examines the approaches presently used by companies and nations to report on the environmental performance of their organisations. The chapter aims to establish the context of the reporting formats used, whether these differentiate between site-specific and generic indicators, and to what extent the methods used might provide a generic, level plane, measure of environmental burden. The environmental reporting guidelines available to organisations are firstly examined, followed by a study of the reporting methods and parameters presently used by nations, industry sectors and individual companies.

1.2 Reporting Guidelines.

The publishing of external environmental reports at both a national and corporate level has been increasing over the last five to ten years, in response to increased concern from society and its scientific community about the state of the environment and the burdens placed upon it by society and industry. This has resulted in an increase in the quantity and frequency of parameters measured at a national level, as well as a rise in the amount of environmental legislation controlling the operation of commercial activities within the nations of the developed world. The companies operating within these nations have experienced additional pressure from their employees, customers, clients and investors, to provide information on their environmental performance. Responding to these pressures, either through accreditation to an environmental management standard or by publishing performance data can now improve the way a company is perceived by its stakeholders and significantly increase its market share. The many companies and nations that do report, however, do so in a wide variety of formats. After a number of studies on the state of environmental reporting within

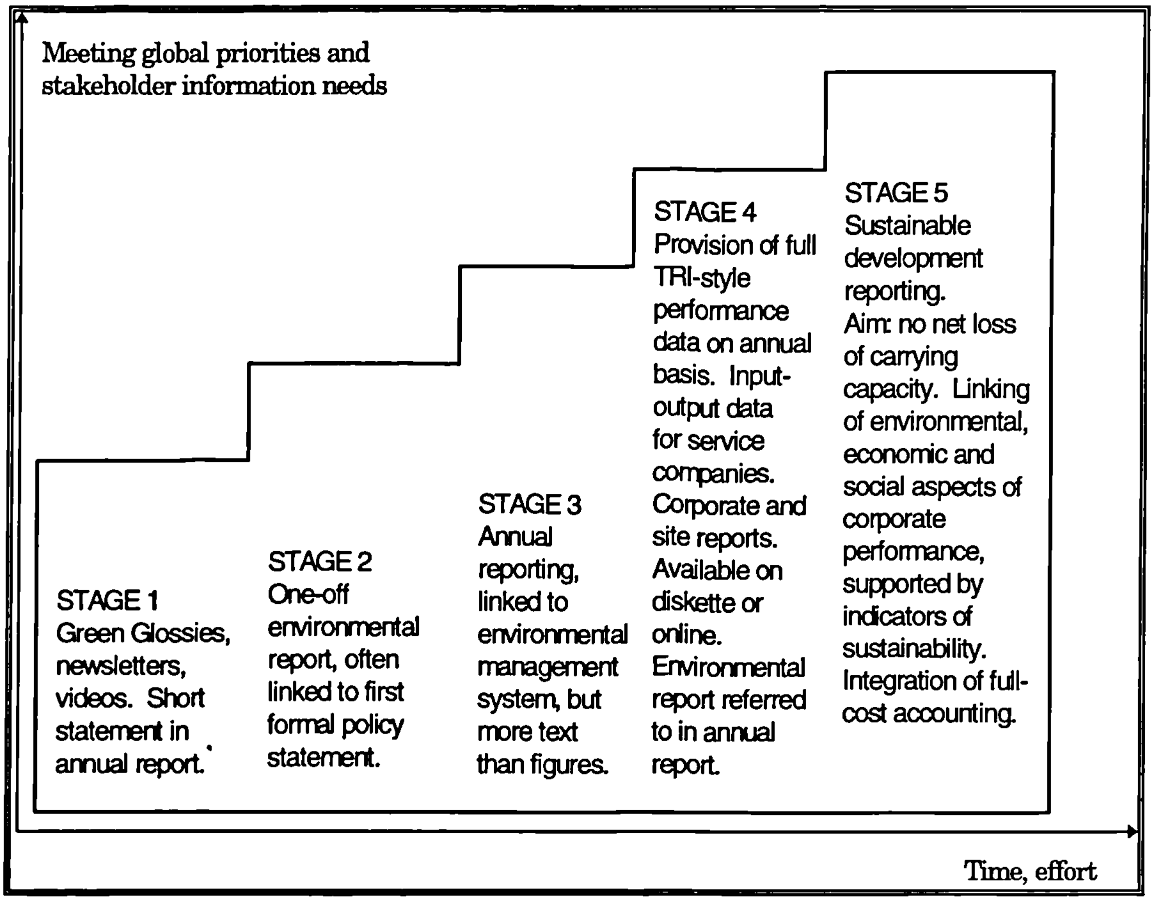


Figure 1.1 - The Environmental Reporting Levels (from DTTI et al. 1993).

the developed nations a series of guidelines have been produced for those producing annual environmental reports.

The reporting frameworks used by companies were surveyed in the Coming Clean report (DTTI et al. 1993). This study identified five levels of environmental reporting, as shown in Figure 1.1. The Environmental Reporting Levels (ERL) move from the production of glossy, word dominated reports and newsletters, up to quantitative reports with indicators of sustainability. To stage 3 of the ERL the predominance of compliance based indicators could be added. The compliance data is then complemented with mass emission data from the input-output data produced at stage 4. This mass emission data represents the first step in the quantification of environmental burden data, past which no companies had moved at the time of the Coming Clean report.

Guidelines on environmental reporting are available from a large variety of sector and international organisations. The majority of these guidelines follow a similar approach, which would take a company no further than stage 4 of the ERL. The principal guidelines presently available have been produced by the European Chemical Industry Council (CEFIC 1993), the World Industry Council for the Environment (WICE 1994), the Public Environmental Reporting Initiative (PERI 1994), and the Association of Chartered Accountants (ACCA 1997). These guidelines provide a series of information categories which should form part of any environmental report. These can best be summarised using the WICE (1994) or ACCA (1997) guides to environmental reporting. These guides group the information into qualitative, management, quantitative and product categories.

The qualitative category includes information on the company and its operations, its environmental policy, views on the environment, targets and objectives, and community relations. Much of this can be related to stage 1 of the ERL. The management category includes information on the environmental management systems in place within the company, which may be split down to include information on the different forms of management employed at each of the company's sites. This sort of information would correspond more closely to stage 3 of the ERL. The quantitative category includes information on the use of energy and natural resources, compliance with regulations, financial indicators and environmental indicators. The information is presently recommended for presentation as mass emission totals together with an explanation of the primary problem to which the emissions contribute. Mass emissions of similar compounds (e.g. VOCs) will be reported as one parameter in this context. Compliance data is included here as a separate sub-category.

Guidance presently does not recommend the use of any impact assessment methodologies to quantify the contribution of the mass emissions to the environmental problems they cause. There also appears to be no conceptual link between the basis for reporting compliance based and mass emission data. The absence of such a framework on which companies can hang their emission data, and one which links into the regulatory framework on which the more site-specific compliance indices are based, may explain the reluctance of companies to move past mass emission data to some measure of potential impact or sustainability, as encountered by the DTTI and UNEP (1994a) studies. Their reluctance to produce potential impact assessment data may also stem from a lack of relevancy of such indicators to everyday operations. As shown in section 2.3, the present links to financial indicators tend to use mass emissions which the engineers and development managers can understand, with impact assessment methodologies seen as too complicated and untransparent. There is also no clear work which shows that the regulations currently imposed on organisations do or do not cover the priority problems to which a company contributes, which would dispel or confirm the need for a separate set of generic impact assessments.

The product category, however, does suggest the use of approaches which use potential impact assessments to examine unit products or functions for improvement or development. Some of the impact assessment techniques used in Ecobalances and Life Cycle Assessment (LCA) might be transferred to assess the organisation as a whole, when based on a rationale or corporate reporting framework. The potential use of these techniques as a generic indicator of environmental performance is discussed in section 2.2.

Beyond the published guidelines, the environmental accounting field has started to examine the potential use of LCA impact assessment techniques as environmental performance indicators. Recent work by Price Waterhouse (Holmark et al. 1995) in Denmark, suggested the use of four impact categories which look at a company's contribution to the greenhouse effect, ozone layer depletion, acidification and nutrification. These categories may provide a suitable set of indicators which can be linked together to derive an index of environmental burden. Forming part of the LCA approach they will be discussed under the integrated environmental management approaches presently available in section 2.2. This ground-breaking work by the accounting community, which traditionally only examines issues on a financial basis (e.g. reductions in energy costs), has recognised the need to monitor and report on mass flow data for an organisation. This need has also been recognised by other writers on environmental accounting (see Gray et al. 1993), who see environmental accounting not just as an exercise in identifying environment related costs and benefits, but also of quantifying the environmental burden of an organisation.

Current environmental reporting guidelines do not provide a rationale or methodology for assessing the potential impact of the mass emission data reported. However, some of the techniques capable of doing this are presently used by organisations for integrated environmental management. As a result they have started to filter through into the environmental reports of a number of forward looking organisations. The current approaches used by these companies, nations and intergovernmental organisations to report environmental data are now examined.

1.3 National and Intergovernmental Reporting.

Environmental reporting at a national and international level presently reflects well on the above guidelines. The reporting by nations and intergovernmental bodies on their environmental performance has seen a marked increase over the last ten to fifteen years, reflecting an increased awareness of the environment by the nations of the developed world.

The first national reports tended to take a compliance based approach, looking only at the concentrations of substances in the environment. The wide range of environmental data available, and approaches used, at this time (UN 1982 & 1983) was combined to derive a set of environmental statistics for Europe & North America in the late eighties (UN 1987). This report also includes information on the physical characteristics of the environment, which might be compared to the stage 1 data requirements in the ERL. Overall most reports could be said to achieve stage 3, using compliance based data sets.

This data set was then supplemented with additional data on the mass emissions of certain key substances from the area under study (DoE 1996, Newman & Foster 1993, OECD 1991, Scottish Office 1994). More recent publications now base their reports on a common framework which recognises the difficulties in reporting on the environmental impacts across areas with variable environmental capacity (EA 1996b, EEA 1995, UNEP 1994b). To simply look at the compliance of an area with environmental quality standards would, therefore, not be justified. In response to this the OECD (1994) has put forward a framework for environmental reporting which uses the Pressure-State-Response (PSR) approach. The OECD approach reports a set of indicators for the pressures on the environment, the resulting state of the environment and the responses which have been taken to try and reduce those pressures. Examples of some of the indicators used within each of the categories are given in Table 1.1.

Table 1.1 - Matrix of Environmental PSR Indicators (Hammond et al. 1994).

Issues	Pressure	State	Response
Climate Change	(Greenhouse Gas) emissions	Concentrations	Energy intensity; environ. Measures
Ozone Depletion	(Halocarbon) emissions; production	(Chlorine) concentrations; O_3 column	Protocol sign.; CFC recovery; fund contribution
Eutrophication	(N, P, water, soil) emissions	(N, P, BOD) concentrations	Treatment connects; investment/costs
Acidification	(SOx, NOx, NH_3) emissions	Deposition; concentrations	Investments; sign. agreements
Toxic Contamination	(POC, heavy metal) emissions	(POC, heavy metal) concentrations	Recov. haz. Waste; investment/costs
Urban Env. Quality	(VOC, NOx, SOx) emissions	(VOC, NOx, SOx) concentrations	Expenditures; transport policy
Biodiversity	Land conversion; land fragmentation	Species abundance comp. to virgin area	Protected areas
Waste	Waste generation - munic., indus., agricul.	Soil / groundwater quality	Collection rate; recycling investment/costs
Water resources	Demand/use intensity - residen., indus., agricul.	Demand / supply ratio; quality	Expenditures; water pricing; savings policy
Forest resources	Use intensity	Area degr. forest; use/sust. growth ratio	Protected area - forest; sustain. logging
Fish Resources	Fish catches	Sustainable stocks	Quotas
Soil Degradation	Land use changes	Top soil loss	Rehabilitation / protection
Oceans/Coastal Zones	Emissions; oil spills; depositions	Water quality	Coastal zone man^{nt}; ocean protection

The pressure indicators cover the environmental burden or pressure that is being exerted on a nation or group of nations. These take the form of mass emission totals of a range of priority chemicals and substances, as well as land and resource use. These indicators can be compared to the mass emission data presently reported by companies which have achieved stage 4 of the ERL.

Indicators of state measure the present concentrations of the substances released in the environment and provide information on the present land use and vegetation type distribution for the area under study. These indicators can be compared to the compliance approach presently used as part of the corporate environmental reporting methods. These state indicators are likely to vary from one region to another depending on the environmental capacity available and the pressure placed upon that capacity. The resulting concentrations could further be compared to regulatory or guidance values for environmental quality to determine the level of compliance or need for action to reduce their concentration. The combination of these two indicator sets acknowledges the interaction and differences between the environmental burden from a company, industry or nation and the variability in the environmental state that these pressures can cause. This variability reflects the differences in environmental capacity available across a given area.

The final indicator set is not an environmental indicator but is used to monitor the extent of action taken or achieved to reduce the pressure indicators and so improve the state of the environment. The response indicator quantifies the actions taken, for example, by measuring the number of sewage services linked to a water treatment works to combat eutrophication from direct input to surface waters. These indicators are provided in addition to the qualitative data on physical characteristics of the area being studied, which has traditionally been reported at the start of all reports. This data has also improved, being supplemented with developments in remote sensing and other land characterisation techniques. With this combination of indicators the PSR framework can be used to allocate an appropriate amount of action, taking into account the ability of an area to carry the pressure placed upon it and the potential for reduction in total emissions or pressure.

Further reporting initiatives, such as the Environmental Pressure Index project being developed by Eurostat for the European Union (CEC et al. 1996), will also be using the PSR approach. However, the Eurostat project is also aiming to tie its indicator set into financial indicators. In order to do this the pressure indices need to be aggregated in some way. Earlier attempts to aggregate environmental data were difficult, due to the disparate indicators which had to be brought together. One attempt to aggregate not just physical emissions, but also pressure and incident indicators, was carried out by Hope et al. (1992) for the UK. Their index combined the global warming potential of NOx, ozone and CO_2, with emissions of SO_2, the number of oil spills, percentage of poor quality rivers, population, tonnes of fertiliser used and thousands of dwellings into a weighted composite index. The separate indicators were normalised to a baseline year and then weighted using the results of a survey on the relative importance of each indicator. The index has also been applied to France and Italy (Hope & Parker 1995).

Much of the present pressure and state data is now reported under certain key headings which represent the group or category of environmental problems to which they contribute (see EEA 1995 for a good example). Within these categories some of the more recent reports also provide information on methodologies that might potentially be used to aggregate the emissions within each category. To date methodologies using global warming potentials, and ozone depletion potentials, which are used to calculate impact equivalents for a series of emissions (see section 2.2.2), have been introduced in reports by the United Nations (UNEP 1994b) and the European Environment Agency (EEA 1995). These reports have not used these aggregation techniques to assess the emission data directly, however. One exception to this can be found in the Netherlands where an aggregated index has been used which is made up of a series of six impact categories, which are aggregated into a single index using the weighting factors based on the percentage of the national target achieved over the previous year (see Hammond et al. 1994). These techniques are also presently being considered as part of the European Statistical Office's System for Environmental Pressure Indices. Consultations are, however, still being made on other possible techniques (CEC et al. 1996).

The impact categories and equivalency factors used in the Dutch index and the UN and EEA reports have been derived from the LCA approach. These categories may provide a useful system for aggregating the mass emission pressure data presently reported using an inter-related set of burden factors, which include global issues while excluding site differences, as part of a generic index. The wide variety of impact assessment techniques available as part of the LCA approach are discussed in detail in section 2.2.

1.4 Sector Reporting.

To date a number of studies have examined the environmental reporting approaches used within sectors of industry, both within the UK and abroad (KPMG 1995, KPMG 1996, UNEP 1994a). However, only the chemical sector, through the Chemical Industries Association, actually reports on its environmental performance as one unit (CIA 1995b). Other work by the European Green Table (1993), has derived a set of sector specific performance indicators.

The Chemical Industries Association is the only industry sector body to produce a set of performance indicators of its member companies. The environmental indicators used measure the discharge of Red List substances and the disposal of Special Waste. The indicators measure the tonnes of material released, with no aggregation or potential impact assessment. The number of sites using some sort of environmental index is also recorded. Other key emissions, which may be reported in the environmental reports of the respective companies, have presently not been included as part of the environmental performance indicator set.

At a European level a set of corporate environmental performance indicators have been derived for five industrial sectors by the European Green Table (1993). Indicators have been derived both for the management and operational side of the sectors covered. The management EPIs cover compliance and quality, with operational EPIs covering actual emissions. The management indicators correspond to stage 3 of the ERL, with operational parameters moving onto stage 4 pressure indices. The pressure indices used, however, only cover mass emissions with no additional aggregation or potential impact assessment. A different set of indicators has been derived for each of the sectors: aluminium smelting, oil & gas exploration and production, oil refining, petrochemicals, and paper manufacturing. This approach reflects the belief that different sectors cannot be compared on a level plane due to differences in the substances emitted.

Application of some of the LCA impact categories used for national pressure indices, and designed to take account of the differences in substances emitted across a region, may provide a standard set of environmental pressure indicators to be derived for industry as a whole. Using a generic set of impact categories or a single index, companies in different sectors could then also be compared. The potential use of these LCA impact categories will be discussed in section 2.2.

1.5 Company Environmental Reporting.

Environmental reporting within companies themselves has seen a marked increase over the last five to ten years. The approaches used have also been evolving during this time with a wide variety of methods and indicators in use. Guidance on the contents of environmental reports is only slowly evolving to include sustainability indicators, and is concentrating solely on mass emissions. As a result the number of companies which have reached stage 5 of the ERL is negligible (UNEP 1994a). This section examines those studies that have quantified the extent and quality of real-world environmental reporting. These will be supplemented by examples of the approaches used by operators within each sector.

There are two good studies available on the state of environmental reporting in the UK and around the world respectively. The first series of reports have been produced by KPMG (1995 & 1996), with a global perspective taken by the United Nations Environment Programme's survey (UNEP 1994a). The KPMG study examined the reports of the FTSE 100 index companies, looking for environmental statements, targets, verification statements as well as quantitative and site specific data. The survey showed a general increase from 1994 to 1995 in the number of environmental reports produced as part of the annual report, with a drop in the total number of separate environmental reports. The quantitative data, however, consisted only of mass emissions with a lack of further impact assessment. An exception to this was an ecological balance produced by AssiDoman for its forestry operations (KPMG 1996).

Those sectors that produced high quality reports up to stage 4 of the ERL covered the chemicals, oil & gas, pharmaceuticals, paper & printing, transport, utilities and textiles sectors. The mass emissions presented by these companies have been supplemented by a limited number of sustainability indicators or aggregation techniques. One of the first attempts to aggregate environmental emission data into an index was carried out by Rhône-Poulenc (Salamituo 1991). Three indices were derived by the company, for water, waste and air emissions. Within each index a series of mass emission parameters are summed using a set of weighting factors that reflect the importance of each parameter based on company policy. Progress from one year to the next is monitored for each index by comparing the results obtained to a baseline year. This approach does not attempt to relate the emissions to each other using physical relationships, relying on expert judgement to inform the weighting factors used.

A slightly different approach to aggregation was taken by the Niagara Mohawk Power Company in the United States (NMPC 1991 & Miakisz 1994). Their index is composed of three sub-categories, within which a weighted score is calculated for waste emissions, compliance and environmental enhancements. Mass emissions to air and water, and land disposal are weighted within the waste category, whereas the compliance category examines the number of fines, complaints and non-conforming discharges the company has been responsible for. Finally, within the environmental enhancements category points are awarded according to the amount of money spent on improvement or abatement projects. The category totals are scaled to allow them to be summed to calculate the composite index. Again, the aim of the work has been to arrive at a single score, rather than calculate the potential impact or pressure from the operations of the company.

Both indices lack a rationale that acknowledges the difference between the pressure and state that can be found across a range of sites owned and operated by an organisation. More recent attempts to supplement the mass emission data reported have, as for the national reports, derived indicators from the LCA impact assessment methodologies (see Chapter 2). Dow-Europe came forward with a potential common impact assessment methodology in its 1994 report (Dow-Europe 1995). The methodology used impact categories for ozone depletion, global warming, acidification, eutrophication, biospheric smog, toxicity dispersion and waste to landfill. However, this methodology has not been continued. A similar approach by the chemicals company ICI has calculated Environmental Burden values for its emissions in the acidity, global warming, hazardous emissions to air, ozone depletion, photo-chemical ozone creation, aquatic oxygen demand and aquatic toxicity categories (ICI 1997a&b). These approaches may provide a useful set of inter-related indicators of environmental burden as part of an environmental performance index. However, both indices lack a rationale or framework that acknowledges the different pressures and states that can be found at the sites operated by these companies.

Those sectors whose impacts are less direct and not directly associated with mass emissions performed less well. The food and drink industry is a good example here. One exception to this is the recently published report by Unilever, the Anglo-Dutch multi-national which is also involved in the chemicals industry. The company has done a lot of work on product and process development, but has only taken its environmental report to stage 3 of the ERL. Within this stage it is, however, a good report, covering the issues and locations for which the company has responsibilities (Unilever 1996).

The use of quantitative reporting by the above sectors has, however, excluded the kind of rationale or framework which supports the national environmental reports even from the front-runners such as ICI and Dow. The reports and publications contain no explanation for why mass emission data should be included, or why such information might be expected to give different results to the compliance parameters also used in the report. Although there is some understanding of the potential and actual impacts which their reports measure, this is not put forward as part of a defined rationale or framework. Much of this is due to the fact that the organisations are responding to external reporting pressures from stakeholders, many of which use different assessment techniques (see section 2.3.2). Furthermore, it is presently impossible to connect the data directly to the financial performance of an organisation, which is still the remains the primary assessment tool with which it is monitored.

1.6 Conclusion.

Examination of the environmental reporting frameworks presently used by both companies and nations has shown the emergence of a potential set of generic environmental impact indicators. These indicators have been introduced but not applied in the environmental reports of national governments and inter-governmental organisations such as the UNEP. The organisations advising companies on their environmental reporting have, as yet, not incorporated these techniques into their guidance, although some companies have started to apply these to the mass emissions data they report. However, within the general company reporting arena there appears to be a lack of rationale and framework for the reporting approaches used, especially for mass emissions, with the belief in a sector specific reporting approach still present.

Environmental reporting at the national and international level, however, is highly developed, a reporting framework that recognises the differences between environmental burden or pressure and the ability of the different local environments within an area to absorb that pressure, resulting in the state of that local environment. Within this framework a set of potential aggregation techniques have been developed to aggregate pressure data on a level, generic plane. However, little use is presently made of the actual techniques themselves, as they have not been applied to the mass emission data available. These techniques may provide a useful set of indicators for a generic environmental performance index. The aggregation techniques used have been derived from the integrated environmental assessment techniques used by companies in developing their products as part of a Life Cycle Assessment. Considering the number of LCAs presently being carried out it is unusual that these techniques have not been used to report on the environmental performance of the organisations concerned. These issues as well as the merits of the integrated environmental management techniques currently available will be discussed in the next chapter.

CHAPTER TWO

Integrated Environmental Assessment

Practice & Potential

2.1 Introduction.

This chapter examines the methods presently available to assess the environmental impact of a single process and the collection of processes used to manufacture a single product. The rationale behind the methods available will be examined to determine to what extent these acknowledge the differences between site-specific and generic approaches. The potential use of these techniques in a generic assessment tool will then be discussed. The chapter starts with an introduction to Life Cycle Assessment, and the variety of techniques used as part of the approach to assess the potential impact of a product or service. Focusing on a single process, the second part of the chapter examines those techniques used to rank the impacts of different process options at a site. Finally, the chapter ends with a discussion of the limitations and potential found within the above approaches and those encountered as part of Chapter 1, to set the scene for the methodology in Chapter 3.

2.2 Integrated Product Assessment Tools.

The principal tool presently used to assess products and materials at a company level is called Life Cycle Assessment. This section examines the history and basis to the LCA approach, going on to examine the techniques used to make an assessment of a product's potential impact. The approaches used to do this may provide a basis for a generic process assessment tool.

2.2.1 The Life Cycle Assessment Approach.

Life Cycle Assessment (LCA) can be seen as both an approach and a specific technique. LCA is best defined as, "an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/re-use/maintenance; recycling; and final disposal" (Assies 1992a, SETAC 1991, SETAC-Europe 1992). LCAs are usually comparative studies, examining two products fulfilling a similar function (Nordic Council of Ministers 1992).

Over the last ten to twenty years studies of this kind have been carried out in Europe, North America and Scandinavia under an array of different names. These include Cradle to Grave Analysis, Cradle to Gate Analysis, Ecoprofiles, Ecobalances, Integrated Substance Chain Analysis, Life Cycle Analysis, Life Cycle Inventory, Life Cycle Review, Product Line Analysis, Product Life Cycle Analysis, Resource and Environmental Profile Analysis and Substance Flow Analysis (Anderson et al. 1993, Boustead 1992, Curran 1993, Elkington & Hailes 1993, Klopffer & Rippen 1992, MacAlaisdair 1993). All these refer to the same basic approach.

The origins of Life Cycle Assessment date back to the late 1960s. During this time energy efficiency, pollution control and solid waste became issues of great public concern. The energy analysis methodologies which were being used at that time were, therefore, broadened to take account of resource requirements, emissions to air and water, and the production of solid waste. The LCA studies undertaken, focused on specific materials and products which were gaining criticism from the public, and were assumed to have hazardous environmental effects. Many focused on packaging and disposable products, which were seen as symbols of a, "throwaway society" (Assies 1992a, Boustead 1992, Elkington & Hailes 1993).

The further development of LCA methodologies has gone hand in hand with an increasingly integrated approach to tackling environmental problems. In the past these were tackled individually, with legislators focusing on specific production processes and sites (Wenzel et al. 1994), and government programmes typically focusing on releases to a single medium (Curran 1993). Proposed solutions often took the form of end-of-pipe technologies to control these releases, resulting in a shift of pollution from one environmental medium to another. With the introduction of Integrated Pollution Control (IPC) under the Environmental Protection Act 1990, a more holistic approach is now required of site operators, although this does not presently extend beyond the process under authorisation (see DoE 1995b). The LCA methodologies developed, not only take account of all the environmental media, but also look at the entire life cycle of a given material, product or service. This should avoid the movement of potential pollution not only to other media, but also to other processes along the product chain. LCA, in effect, aims to optimise the product with respect to the environment (Fava & Page 1992), by minimizing the environmental burden per unit of product. This holistic approach means that some of the studies have also included social and economic considerations (Elkington & Hailes 1993, Steen & Ryding 1992).

In response to this more integrated approach by governments and academics, a number of similar approaches have been developed by industry for product development and to a lesser extent process management. Firstly, the design of new products has stimulated the likes of Integrated Life Cycle Cost Assessment (Warren & Weitz 1994), Design For Recyclability, Design For Compostability

(Benda et al. 1993), Design For Environment, Design For X, where X = manufacturability, measurability etc. (Keoleian & Menerey 1994). Other approaches, geared more at the management of processes, are Paradigm 'E'- Competing on Ecology (Tipnis 1994), Integrated Life Cycle Management (Cohan & Gess 1994), Environmental Optimisation (Potter & Isalski 1993), Integrated Modelling of Material Flows and Energy Systems (Sundberg & Wene 1994), TQM - Cradle to Grave (Wahl & Bersbach 1991), Cradle-to-Grave Material Management Puckett & al. 1991), and Integrated Environmental Management, which aims to combine quality, health and safety, and environmental management systems (Streatfield 1993). Specific process management techniques will be discussed in more detail in section 2.3. The above approaches generally do not perform any impact assessments as part of their work, being built up of a variety of screening methods or mass release optimisation methodologies. The proponents of LCA believe that its methodologies can, and will, play a major role in developing many of these techniques further.

The number of methodologies used in carrying out LCAs are about as varied as the names for LCA. They have been examined in the form of a literature review by a number of research institutes (Andersson et al. 1993, Nordic Council of Ministers 1992). The results from these reviews have been brought together by the Society for Environmental Toxicology And Chemistry (SETAC) into a number of expert workshops. A 'Framework Document' and 'Code of Practice' have been produced from these workshops, which describe the general principles and framework that has been agreed (SETAC 1991, SETAC 1993b). However, opinions still differ among practitioners as to the use of specific techniques within the framework itself. Other attempts to standardise the LCA methodology are being performed by the International Standards Organisation Strategic Advisory Group on the

Environment (SAGE), for application in the EC Eco-label scheme, the Comité Europeén de Normalization (CEN), the United States Environmental Protection Agency and the Canadian Standards Association (Weidema & Christiansen 1994). In response to the many approaches and terminologies being used by practitioners, ISO has now developed an international standard for the LCA approach (ISO 1997). Additional publications about the LCA methodology have also been produced by the Nordic Council of Ministers (1992), the USEPA (Vigon et al. 1994), CML (Guinee et al 1992a&b), and the CSA (1992a&b). These documents generally conform to the framework given by SETAC. Future development work by the above organisations is now being co-ordinated through the LCANET project which has developed a document on the state-of-the-art LCA methodologies and future research needs (Wrisberg et al. 1997).

2.2.2 The Life Cycle Assessment Methodology.

Life Cycle Assessments are studies of the environmental inputs and outputs of a product or material along the whole of its life cycle. This life cycle should, ideally, include every economic process related to the production of that product. In the SETAC (1991) framework document, the life cycle of a product is broken down into six distinct economic activities: raw materials acquisition; manufacturing, processing and formulation; distribution and transportation; use/re-use/maintenance; and recycle and waste management (see Figure 2.1). Note the separate component for distribution and transportation, which is included as a specific process to get the finished product to the consumer, as opposed to the transport which must take place to get the product from one process to another. At a conceptual level each of the components will have inputs from, and outputs to the environment outside the system boundary.

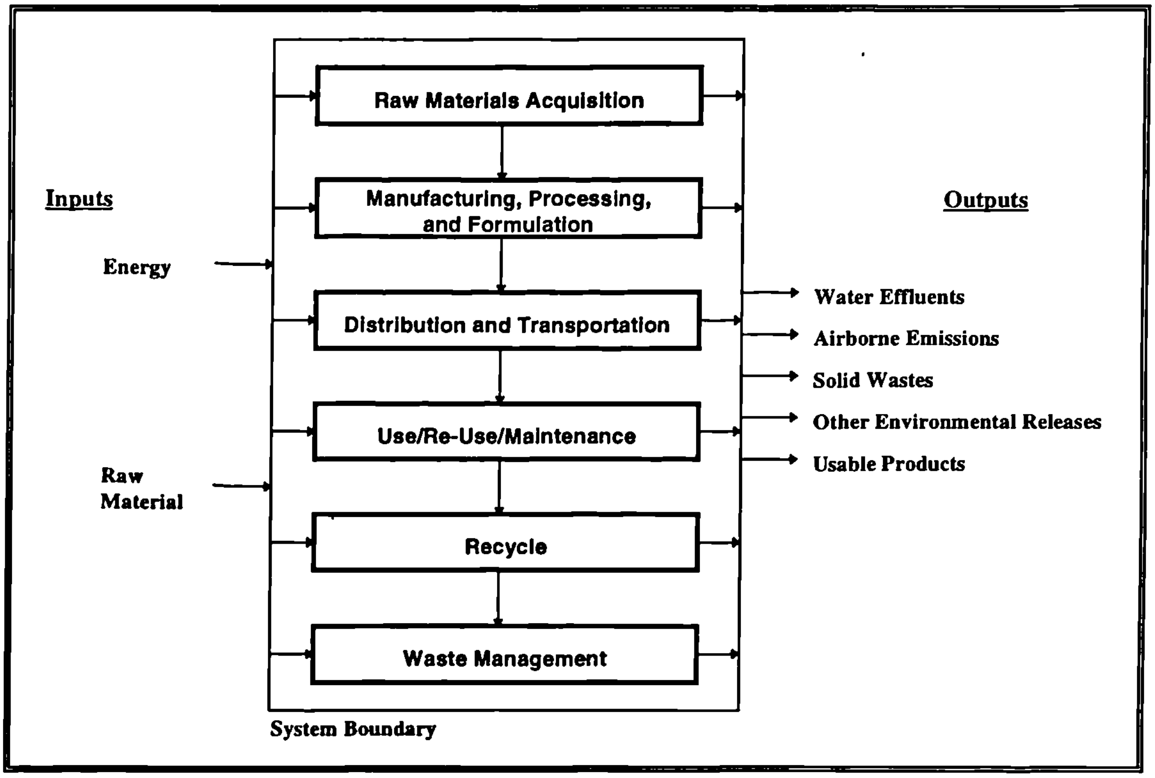


Figure 2.1 - Example of Process Activities for a Product (SETAC 1991).

To analyse and assess the inputs and outputs to the environment the framework used by SETAC is most often applied. This splits the assessment down into three separate stages: Inventory Analysis, Impact Assessment and Improvement Assessment. This framework applies primarily to environmental LCAs, although some LCAs have also included components of social and cost LCAs into environmental LCAs. However, this is an area of present debate, with some practitioners believing that social and economic assessments should be performed separately, as shown in Figure 2.2 (Assies 1992a, SETAC 1991, SETAC-Europe 1992). In looking to derive a physical measure of environmental burden, these socio-economic factors would need to be excluded.

2.2.2.1 Inventory Analysis.

The first stage of an LCA is the inventory analysis. This is, "The process of compiling the amount of natural resources and energy taken in by the system and the amount of wastes irretrievably discharged to the environment due to the production of one unit of a given product," (Andersson et al. 1993). The inventory stage is the most well developed part of the LCA methodology and has a high degree of overall consensus. The principles and methodologies have been discussed in a number of key texts (Guinee et al. 1992, Nordic Council of Ministers 1992, SETAC 1991, SETAC-Europe 1992, Vigon et al. 1994).

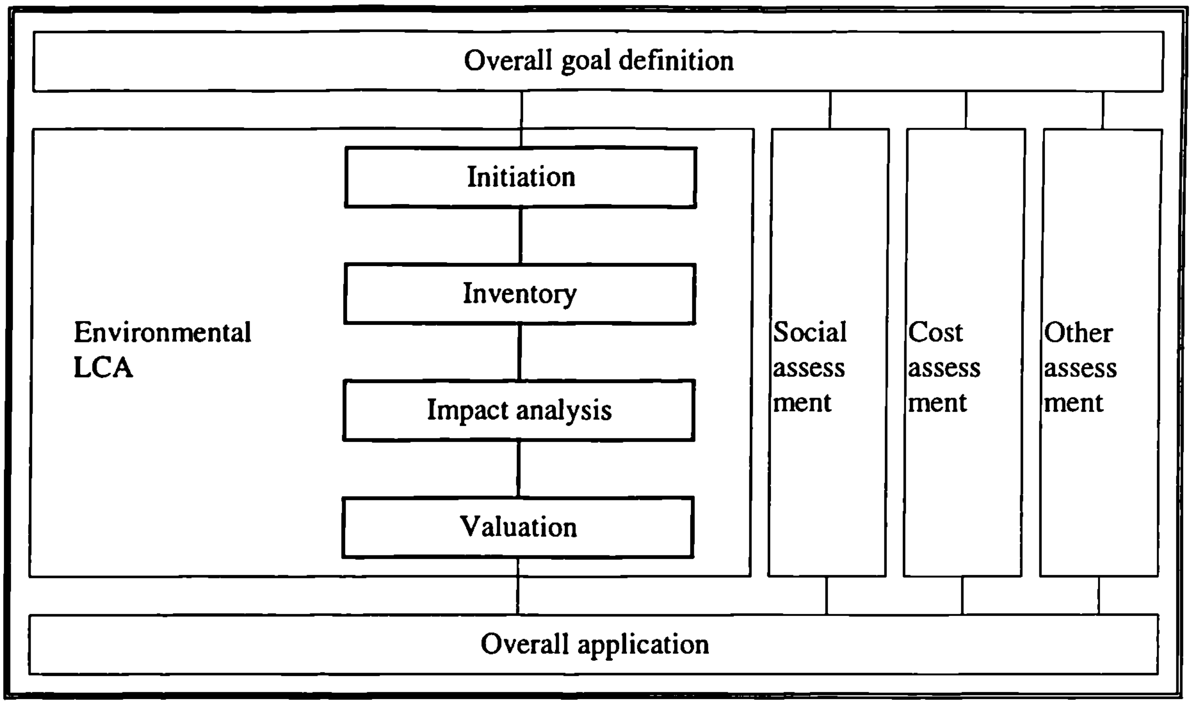


Figure 2.2 - The Environmental and Other LCAs (Assies 1992a).

The inventory stage can be split down into the following components:

(i) <u>Scope of Study.</u>

The scope of the study defines the breadth and depth of analysis that will be needed to fulfil the stated purpose. This section sets the scene for the data collection and how this data will be used. The participating and financing bodies should also be stated.

(ii) Product Definition.

The product and any alternatives are the central part to any LCA. To allow alternatives to be compared a unit of service or function given by that product is defined, called the "Functional Unit". An LCA only analyses this given amount of service or function. The actual total consumption of this service, however, is not studied. For example, in order to be able to compare the use of disposable packages and returnable bottles for milk the unit of functionality might be set at, say, "the packaging of 10,000 litres of milk." This would allow the total number of return cycles to be included in the analysis. Other factors which must be examined are the quality of the alternative products, or fitness for purpose, which must be equal.

(iii) System Definition.

The third component concerns the boundaries that are going to enclose the product system. The product system itself is represented as a process tree. The boundary must be defined in relation to other product systems and the environment. This is a critical stage in an LCA as it determines the amount of data that must be collected. Decisions must also be made as to the allocation of material and energy flows to the product system. This occurs primarily where a product chain passes through processes that produce multiple products. Other factors that are considered are the geographical limits to the study, the technological level of the processes and the inclusion of process equipment in the analysis. The data is then collected in light of the above definitions.

(iv) Data Collection.

The collection of data is normally guided by a checklist for transparency and consistency. The inventory is fundamentally an energy and mass balance of the product system, with the level of detail determined by the original purpose and system definition of the study, and more importantly by the availability of data. This has been a major problem in performing many LCAs. As a rule the overall system is analysed only to such a level of detail that the sub-systems correspond to operations for which data can be obtained. In gathering data some analysts will exclude certain material inputs, saying that as their mass is small, their contribution to the overall system is insignificant (Boustead 1992). This can be very dangerous, considering that the functional unit gives no indication of the total volume produced, only that attributable to the functional unit. A recent study by Lave et al. (1995) suggests that the exclusion of those inputs which represent less than 5% of the material input to a system, can result in the exclusion of the majority of the indirect impacts from the manufacture of that product. Another area of disagreement is on the treatment of missing data for which methodologies vary widely. Missing data may be substituted by 'worst-case' data, average data for a given technology, or the detection limit for the equipment concerned (Andersson et al. 1993). Many LCAs to date will use a mixture of site-specific data for the process owned by the study financier or practitioner, supplemented by industry average data for the materials supplied. This can give misleading results concerning the environmental burden from suppliers and waste management companies associated with the primary process.

The sources of data used can also vary widely and are not always acknowledged. For any study, enterprise specific data is recommended but is not always available. Other sources used will be interviews, primary and secondary literature, technical and legislative norms, theoretical models and databases (Andersson et al. 1993, Vigon et al. 1994). A number of databases are available as a source of secondary data, although they tend to contain only average data for a typical technology.

These include IDEA, Simapro, Oekobase, KCL-ECO, PIA and LCA Inventory Tool (Andersson et al 1994, Dall'Acqua 1994, Elkington & Hailes 1993, Karna et al. 1993, Keoleian & Menerey 1994). All but the first are intended as LCA software tools as well as a database.

Despite the consensus on methodology the inventory component still has a number of problem areas. First and foremost, the quality of the data coming out of an LCA is determined by the quality of that going in. It is here that problems occur. Information is often not available on the age of the data, the time period during which it was collected and at what frequency this occurred. Neither is information given on the completeness, representativeness, natural variability or uncertainty of data (Andersson et al. 1993, Vigon et al. 1994). This often leads to the obtained results being called unreliable. More detailed studies by some LCA users have shown that there can be a significantly large amount of variation for a given technology, which is not acknowledged as part of the assessment (see Ayres 1995, ENDS 1992, Fouhy 1993, Lee et al. 1995, Miner & Lucier 1994, Nordic Council of Ministers 1995a, Virtanen et al. 1995). A study based on the average data only may, therefore, provide invalid results in the absence of variability data. Data access is another problem together with the misuse of data for commercial ends (Charlton & Howell 1992). The definition of the product system and its boundaries has also been a difficult problem. It is easy to get into a situation where the whole world is being studied, or where highly significant sub-systems are left out of the analysis. As a result LCA is often an iterative process with assumptions and boundaries being adjusted as more information is gained.

The final inventory provides a catalogue of those inputs and outputs at the product/environment interface, usually in the form of a table. This list does not say anything about environmental effects due to those releases. This list might be compared to the mass release inventory of a company or that produced as part of the pressure indicators for national environmental accounts. In certain cases it will be clearly obvious as to which of the products being compared is "best". In this case less is best. The inventory becomes less meaningful, however, when the product system interacts with all the media and with a multiple of inputs and outputs to each. It is then important to get an idea of the relative importance of each of the inputs and outputs. It is here that the impact assessment stage of LCA is used.

2.2.2.2 Impact Assessment.

The impact assessment stage of LCA is presently under active development. There are a wide variety of approaches available, but no consensus on a standard approach has yet been reached (Curran 1993, De Smet 1992, ENDS 1994b). The impact assessment stage aims to provide further information as to the contributions made by the inventory results to different environmental problems. This often results in a decrease in the amount of information available, a factor which has received a lot of criticism. Many LCAs have, therefore, not gone beyond the inventory stage. However, in terms of effects upon environmental processes, the information obtained from an impact assessment is more useful than the mass emission data available in the inventory table.

The Conceptual Framework for Life Cycle Impact Assessment (SETAC 1993a), divides the impact assessment stage up into three components: classification, characterisation and valuation. Classification is, "the process of assignment and initial aggregation of data from inventory studies to relatively homogeneous stressor categories (e.g. greenhouse gases or ozone depleting compounds) within the larger impact categories (i.e. human health, ecological health, and resource depletion)." Characterisation consists of, "the analysis and estimation of the magnitudes of potential impacts on the ecological health, or resource depletion for each of the stressor categories, derived through application of specific impact assessment tools." Finally, valuation involves, "the assignment of relative values or weights to different impacts and their integration across impact categories to allow decision makers to assimilate and consider the full range of relevant impacts across impact categories" (SETAC 1993a). An example of this process is given in Table 2.1 using the "environmental themes" method.

The classification and characterisation methods presently used primarily rely on scientific approaches for aggregating emissions into a variety of impact categories. The valuation techniques used to weigh these categories, however, employ a variety of social and economic weighting factors, which do not represent the actual physical relationships between these categories.

The different approaches being used are best summarised by looking at three of the most widely used techniques: the critical flow method, the weighted environmental theme method and the EPS method.

(i) The Critical Flow Method.

The critical flow method was introduced in some work by the Swiss Environmental Protection Agency (BUWAL 1990). The methodology uses a set of eco-factors for each substance emitted, which are calculated using the present flow of that substance in a given area divided by the critical flow for the material, as shown in Equation 2.1.

Equation 2.1- Calculation of the Eco-Factor for a Substance.

$$EF_s = (1/F_{k,s}) * (F_s/F_{k,s}),$$

where,

EF_s = Eco-Factor for substance, s.
F_s = Present flow of substance, s, emitted.
$F_{k,s}$ = Critical flow of substance, s.

The critical flow represents the maximum tolerable flow of a substance in an area or catchment. The approach was derived from releases to surface waters, but can also be applied to air emissions, using critical loads for the relevant parameters. The critical flows used normally represent the sustainable load for a catchment or area, but may also be substituted using policy targets. The second approach is often called the Eco-Scarcity method.

Equation 2.2 - Calculation of the Eco-Score for a Product.

$$E_{Total} = \sum_{1}^{n} Q_s * EF_s,$$

where,

E_{total} = Eco-score for product.
Q_s = Quantity of substance, s, emitted.
EF_s = Eco-Factor for substance, s.
For all substances, s = 1 ...n.

A final score is calculated by multiplying the amount of each substance emitted, by its eco-factor and summing across the results, as shown in Equation 2.2. By calculating the proportion of the critical flow of a substance which has been used up by present emissions the critical flow method "values" each emission by comparing it with the quantity of present flow within the area of study.

This is a more practical valuation approach to weighing environmental impacts than some of the more socio-economic methods used. However, the method is very much site or region dependent in nature. This also makes it very difficult to include the many global issues into the assessment, although this could be achieved, for example, by splitting down the emission targets agreed as part of international treaties, into critical flows for different parts of a country. This kind of technique is likely to be more useful as a catchment management tool for assessing the performance of industrial operators at a local level. Despite its site or area specific nature it has still been used in many LCA studies.

(ii) The Weighted Environmental Theme Method.

The weighted environmental theme method is based on the idea, that emissions can be scientifically classified, into a limited number of environmental effect categories, where the importance of one effect has to be compared with the importance of another. The methodology was developed by McKinsey & Company, The Centre for Environmental Science in Leiden and the Dutch National Institute for Health and Environment (Guinee 1992a&b).

Table 2.1- Environmental Effect Categories Suggested for Use in LCA.

Environmental Effect	Effect Score	Unit	Characterisation Factor
Depletion of abiotic resources	abiotic depletion	-	1/reserves
Depletion of biotic resources	biotic depletion	yr^{-1}	DBF
Enhancement of greenhouse effect	greenhouse effect	kg	GWP
Depletion of the ozone layer	ozone depletion	kg	ODP
Human toxicity	human toxicity	kg	HTP
Aquatic ecotoxicity	aquatic ecotoxicity	m^3	AETP
Terrestrial ecotoxicity	terrestrial ecotoxicity	kg	TETP
Photochemical oxidant formation	oxidant formation	kg	POCP
Acidification	acidification	kg	AP
Nutrification	nutrification	kg	NP
Waste heat	aquatic heat	MJ	1
Odour	malodourous air	m^3	1/OTV
Noise	noise	$Pa^2.s$	1
Damage to ecosystems	damage	$m^2.s$	1
Victims	victims	-	1
Radiation	-	-	-
Final solid waste	-	-	-

The method follows the steps outlined in the SETAC framework document. The inputs and outputs to the environment of the analysed products are first classified into a wide range of possible environmental themes. Those used as part of the Guinee (1992a&b) publication are given in Table 2.1. A number of additional categories have been suggested, which may also be included as part of an LCA Impact Assessment. These include radiation (Heijungs 1994) and final solid waste (SETAC-Europe 1992).

Having assigned each of the inventory releases to its relevant categories the emissions are characterised to derive a total contribution to the impact category. This is generally achieved by multiplying the relevant parameter by a characterisation or equivalency factor, as shown in Equation 2.3.

Equation 2.3 - Calculation of Effect Category Totals.

$$E_i = \sum_{1}^{n} EF_{a,i} * Q_a,$$

where,

E_i = Effect category, i.
$EF_{a,i}$ = Equivalency Factor for substance, a, on effect, i.
Q_a = Quantity of substance, a, released.
For all substances, a = 1 ...n.
For all effects, i = 1 ... z.

The equivalency factors represent the potential for the substance released to contribute to the impact category relative to a reference substance. The impact equivalents are then summed within each category to give a equivalency total for the environmental theme.

Some of the present categories do not have a characterisation factor, either as equivalents or otherwise. These include abiotic and biotic resource depletion, radiation, waste heat, odour, noise, damage, victims, and final solid waste. A number of these categories also represent aesthetic categories, which have no direct physical effect on the environment. These include abiotic resource depletion, which has primarily been included as an “environmental issue”, but does not constitute a direct physical effect. The emissions and impacts from the extraction process of the abiotic resources will already be assessed during an LCA. The absence of the material will, generally not have a direct effect, except perhaps on pedogenesis, for removals of material near the surface.

Finally, odour and noise can have a detrimental psychological effect, but do not constitute a physical or toxicological hazard. Again the issue is an emotive site-specific one, which can change from one area to another. In a location where the employees live around an industrial site people will generally be used to a certain amount of smell and noise. The fact that they work at the factory and know about the process, tends to increase their tolerance. Where the residents surrounding an industry do not work there, this trend will be reversed. Such issues have a strong social nature, and should be treated as part of the social dimension of an LCA. Presently, however, this part of LCAs is very weakly developed with no framework for a purely ecological environmental LCA. The definition of environment differs between practitioners and often includes effects on the surroundings in general. This can also be said for the environmental themes or issues covered as part of the impact assessments.

With the exception of some aesthetic categories the environmental theme method is the most purely physical form of environmental LCA. It also calculates the potential impact of a set of releases on a range of generic impact categories, providing a good level plane assessment tool. Valuation of the categories presently occurs using techniques from the social sciences. Most often the categories are normalised by dividing them by the category total for the world. The fractions obtained are then summed using weighting factors based on the importance of the categories relative to each other. These weightings may be derived from experts (see Wilson & Jones 1994), or research on the importance of the categories to society or the economy. No physical weighting factors are presently available based on the relationships between the categories.

(iii) The EPS Method.

The Environmental Priority Strategies (EPS) methodology was developed by the Swedish Environmental Research Institute (Steen & Ryding 1992). The technique consists of two separate indices, which are combined to give a final value, or Environmental Load Unit, from the Resource Index and the Effect Index.

The Resource Index (RI) measures the usage and irreplaceability of a given material as shown in Equation 2.4.

Equation 2.4 - Calculation of the EPS Resource Index for a Material.

$$RI_a = \frac{Ba}{Aa} * C,$$

where,

RI_a = Resource Index for material, a.
A_a = World-wide per capita finite natural resources of material, a.
B_a = Estimated resource irreplaceability of material, a.
C = A scale factor to match the emission indices.

The Effect Index (EI) for a given release is calculated by combining a set of effect categories, as shown in Equation 2.5. These categories measure the physical effect of the substance together with the socio-economic factors on how they might be reverted.

Equation 2.5 - Calculation of the EPS Effect Index for a Substance.

$$EI_b = F1_i * F2_i * F3 * F4_i * F5_{i,b} * F6_{i,b},$$

where,

$EI_{i,b}$ = Effect Index for substance, b, and effect, i.
$F1_i$ = Ability and will of society to pay to avoid an effect, i.
$F2_i$ = Frequency or average intensity of the effect, i.
$F3$ = Affected area or population, as percentage of total area.
$F4_i$ = Duration of the effect, i.
$F5_{i,b}$ = Contribution of 1kg of substance, b, to the effect, i.
$F6_{i,b}$ = Cost for the elimination of 1kg of substance, b.

Finally, the material usage and substance emission data for the system under study are put into the indices to calculate the ELU, as shown in Equation 2.6.

Equation 2.6 - Calculation of the Environmental Load Unit for a Product.

$$ELU = \sum_{1}^{n} (RI_a * U_a) + (EI_{i,b} * E_b),$$

where,

ELU = Environmental Load Unit for product.
U_a = Quantity of material, a, used.
E_b = Quantity of substance, b, emitted.
For all materials, a = 1 ...n.
For all substances, b = 1 ...n.
For all effects, i = 1 ...n.

The EPS system combines environmental effects with those of socio-economic variables such as willingness to pay and cost of prevention. The technique will also take account of the intensity and duration of an effect, which must be placed within a regional context, in this case that of Sweden. This also applies to the valuations put onto the effect by society's willingness to pay. The EPS method, therefore, does not perform very well as a pure and generic potential environmental impact assessment tool. The effects considered by the methodology can vary, but generally include effects on the biodiversity, biological/agricultural production, human health and resources of the area under study. The methodology ties the units within these categories together using the socio-economic factors, with little characterisation of the effects within their own categories based on known physical relationships. As a result this approach would be less useful as a purely physical environmental index.

2.2.3 The Use and Abuse of Life Cycle Assessment.

The early use of Life Cycle Assessment in all its shapes and forms has primarily been, "the preserve of big powerful companies operating in high profile sectors like packaging and chemicals" (Elkington & Hailes 1993). Other than in a general form, discussing the major issues encountered in product or material assessments, the findings and methodologies of these LCAs have not been published for public consumption. Of the hundred LCAs carried out in the USA at that time, most were privately funded and were not made available to the public (Curran 1993). Of the 70 LCAs carried out by Ecobilan, a consultant in France, only 3 have been published (Elkington & Hailes 1993). One recent publication, sponsored by Albright and Wilson, "The Phosphate Report," does give a full account of how the study was carried out, what the results were and how these were obtained (Wilson & Jones 1994). Such studies have, however, received a lot of criticism, as the results often appear to support the products of the sponsoring organisation, or contradict a previous study on the same subject (Assies 1992b, ENDS 1994a, Fawer 1994).

The products and materials covered by LCAs are now wide and varied. LCAs have examined everything from aluminium to wood pulp and diapers to food products. A good summary of the areas in which LCA has been applied has been produced by Elkington & Hailes (1993) and the Nordic Council of Ministers (1992). More recent work has focused on those areas receiving attention in the world's media. A good example of this is the work done on paper (see Karna et al. 1993, SFIA 1995, Virtanen & Nilsson 1993) and other wood derived products (see Richter 1993, Miner & Lucier 1994), especially in the context of waste management and recycling (see Craighill & Powell 1996, Emmerson et al. 1995, Finnveden et al. 1995, Hunt 1995, Johnson 1993, White 1995). Other areas include the detergents sector (see Fawer 1994, Hindle et al. 1993, Pittinger et al. 1993, Wilson & Jones 1994), food products and their packaging (see Andersson et al. 1994, Wegener Sleeswijk 1993), and a wide range of fuel and energy alternatives for the generation of electricity

(Sorensen 1994, Virtanen et al. 1995) and the provision of transport (see Eriksson et al. 1996, Field et al. 1994, Fulton 1992, Furuholt 1995, Gover et al. 1996).

In looking at these products the results of the LCAs have primarily been used to (Andersson et al. 1993, Elkington & Hailes 1993):

(a) Define and compare the environmental burdens for finished products.
(b) Guide the development work on new/alternative products.
(c) Provide environmental information to consumers.
(d) Establish criteria for environmental labelling schemes.

The data provided for these high level, product orientated LCAs originates from sites operating at different locations. The wide range of environmental capacities likely to exist at these sites suggests that a generic impact assessment should be used if a valid comparison is to be made between similar products. However, within the LCA community the use of impact assessment methodologies is still unresolved, with some studies using a site-specific and others a generic approach. Some practitioners have suggested that a twin-track has developed within the impact assessment phase of LCA (White et al. 1995). None of the practitioners, however, acknowledge the differences between site-specific and generic impact assessments, and the potential effects these can have on the results obtained. Those opposed to the generic approach often complain that study results are not relevant to the processes and priorities at their site, while those opposed to the site-specific approach argue that the product comparison is invalid due to regional differences. A framework is clearly needed, therefore, to inform the use of assessment tools at different levels of decision making. Once data from more than one site is being considered, the effects of differences in environmental capacity could start to affect the results from area or site-specific assessment techniques. If this is the case it is imperative that a generic tool is used when comparing the results of comparative studies. The optimum results, however, may not fit into the environmental capacity available at some of the sites along a product chain. As a result a decision to change the location of a site may have to be made.

A second factor which can significantly affect the results of these studies, and which has only been marginally addressed, is the variability of the data. This variability relates primarily to the differences in emissions from the wide range of process operators or process types used within a sector for which LCA data is available. Other sources of variability include uncertainties in the data and impact assessment methods used, or the management of the processes contributing to the sector average itself. Present LCA studies for a wide range of material use alternatives have only used average data to assess the effects from the extraction and production of the materials used in the process of the sponsor. This approach can give highly misleading results, when the potential variability is ignored. Decisions based on these results may, therefore, actually increase the total burden of a product by choosing a new material based on sector average data. A number of articles have shown that the use of different data sources or averages can give significantly different results (Ayres 1995, Fouhy 1993, Lee et al. 1995, Nordic Council of Ministers 1995a&b). Emission data from the sponsor of a study is often more readily available than that from its suppliers, and less so further up the product chain. To overcome this problem emission data from a series of databases is used as an estimate. The industry associations which supply this data, however, do not provide variability data, so as to protect its member companies. As a result a valid comparison of the range of burdens possible for a material or product cannot be made.

A good example of the potential variability within a sector is the Scott study, which examined the pulp manufacture emissions from the physical and chemical pulping processes used by its suppliers (ENDS 1992, Fouhy 1993). The study showed that there was a large difference not only between the two processes used, but also between different suppliers within the same process group. If a sector average was used to approximate this contribution from the different process groups, an invalid estimate for the environmental burden from the paper cycle for the company would have been calculated. Other work has shown that the use of average regional electricity generation emission factors from LCA databases can also give significantly different results for product LCAs, depending on where the product is produced and used (Nordic Council of Ministers 1995a&b, Virtanen et al. 1995). This issue of site-specific emission data and generic impact assessment is one that needs to be resolved. If data is to be used to compare the burdens from the manufacture of a product by different companies, their material use data must be representative of the suppliers that they use, or show the variability between the potential suppliers from which they might source material for a new material or product. At present these differences are hidden behind sector average data. It is the impact assessment phase, however, which should be carried out on a level plane, using a generic or average impact assessment tool.

A final problem from LCA use and abuse relates to the setting of boundaries by studies. This has been a long-standing problem for LCAs, as there can be a tendency to start assessing the whole world. Cut-off points are therefore devised for material sourcing, with utilities being included or excluded from all parts of a potential study. These cut-off factors have been shown to be significant in certain cases based on large-scale input-output analyses carried out using national data by Lave et al. (1995). The inclusion or exclusion of utilities into this equation can also have significant effect on the outcome of an assessment. A study by Lee at al. (1995), for example, showed that the exclusion of factory electricity usage could change the perceived primary environmental burden for the manufacture of a washing machine from the producer onto the user. If these utilities were included, the primary burden would revert back to the producer.

These issues have led to a reduction in the credibility of many LCAs performed to date, with critics pointing out that, "the outcome of an LCA is the result of the input and the input is the result of the preferences of those who are paying for the study."

2.2.4 Conclusion.

Life Cycle Assessment is a very young science which is still in its infancy (Curran 1993). It has been called everything from an environmental panacea, to a public relations gimmick (Kuta 1992, Young & Vanderburg 1994). The main problems within the inventory component concern data quality and availability, with a general consensus on the methodology among practitioners. Within the impact assessment component consensus has yet to be reached on how to manipulate that data (ENDS 1994b). This concerns both the methods to be used for an impact assessment, and for the valuation of the results obtained from this part of the technique.

As a result of these problems and disagreements LCAs have received criticism that the results are not objective, and that they too often reflect the interests of the commissioning companies. Critics also point out that the methodology is still developing, and is therefore not suitable for use. Much of the controversy in relation to LCA reflects the fact that well before anyone has produced a totally satisfactory LCA there is already discussion about how the process can be extended (Elkington & Hailes 1993). This question of appropriateness is a difficult one, but can best be answered by trying the techniques out first. The same might also be said for the development of LCA. Application of the methodology as it stands to real-life situations may help us identify those areas of LCA that most need to be developed.

2.3 Integrated Process Assessment.

The use of integrated process assessment methods has more recently seen an increase in use, in line with the adoption of legislation within the UK that requires companies to take an integrated approach when assessing new or changes in developments. In addition to the legislative drivers, a number of additional pressures have been forcing companies to assess and manage their processes. These pressures from customers and investors have led to the development of a range of assessment and management tools. To demonstrate this a conceptual Information Life Cycle of a process or site can be defined, along which different approaches are used to assess and manage that process (see Figure 2.3). The life cycle starts with an environmental impact assessment to determine whether the environmental burden from the site can reasonably be absorbed by the local environment. This assessment is then followed by what will be a recurring series of assessment tools through its life cycle. The core assessment techniques are those used to manage the site operations through the adoption of an Environmental Management System (EMS), often by accreditation to standards such as EMAS, BS7750 or the recently published ISO14001. These systems are also used to provide customers and clients with product, process or company information. The methods used as part of an EMS are discussed in section 2.3.1. External assessment by potential investors, often based on the information provided in site or company reports, uses a range of tools. These are discussed in section 2.3.2. The process information life cycle starts and finishes with site application tools which are still under development by the regulatory authorities in the UK and the EU. The process assessment techniques presently available are discussed in section 2.3.3.

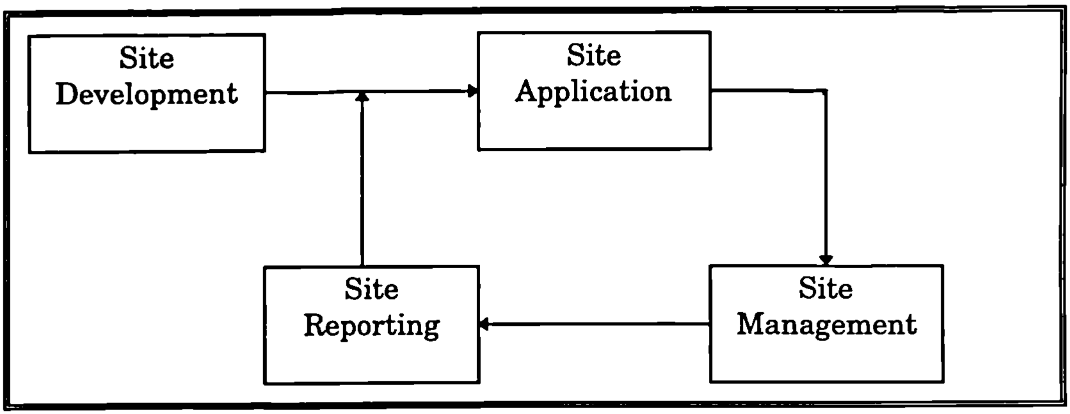
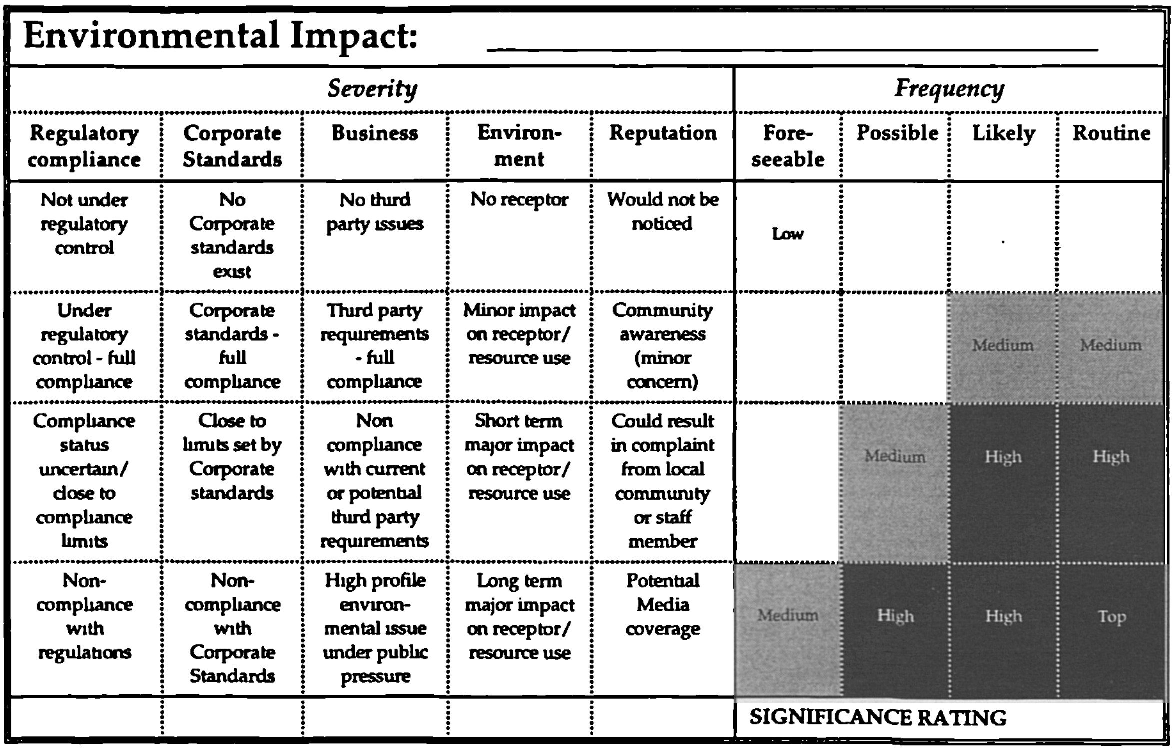


Figure 2.3 - The Information Life Cycle of a Site.

2.3.1 Internal Environmental Management & Information Systems.

The use of formal environmental management systems by industry has seen a dramatic rise in the last five years, with initiatives put forward by standardisation bodies in the UK and Europe. The UK's British Standards Institute (BSI 1994) produced BS7750 Environmental Management, with the EC putting forward the Eco-Management and Auditing Scheme - EMAS - (DoE 1995a). These two standards have now been superseded by a global standard from the International Standards Organisation, ISO 14001 (ISO 1996a). This standard has seen a much larger uptake than the original European standards, especially in East Asia.

As part of these standards an operator must carry out an assessment of environment effects for prioritisation. The methods used to achieve this are generally very qualitative and subjective, based on a risk assessment approach. Their coverage, however, can be greater than some of the more quantitative assessment tools used elsewhere. Indirect effects such as car use emissions and minor oils spills tend not to be covered by IPC and LAAPC applications. A good example of one of the subjective assessment tools used is a matrix system (Aspinwall & Company 1997) which assesses a range of environmental aspects (see Figure 2.4).



Environmental Impact: ____________________

Severity					*Frequency*			
Regulatory compliance	**Corporate Standards**	**Business**	**Environ-ment**	**Reputation**	**Fore-seeable**	**Possible**	**Likely**	**Routine**
Not under regulatory control	No Corporate standards exist	No third party issues	No receptor	Would not be noticed	Low			
Under regulatory control - full compliance	Corporate standards - full compliance	Third party requirements - full compliance	Minor impact on receptor/ resource use	Community awareness (minor concern)			Medium	Medium
Compliance status uncertain/ close to compliance limits	Close to limits set by Corporate standards	Non compliance with current or potential third party requirements	Short term major impact on receptor/ resource use	Could result in complaint from local community or staff member		Medium	High	High
Non-compliance with regulations	Non-compliance with Corporate Standards	High profile environ-mental issue under public pressure	Long term major impact on receptor/ resource use	Potential Media coverage	Medium	High	High	Top
					SIGNIFICANCE RATING			

Figure 2.4 - Ranking Matrix for Environmental Aspects (Aspinwall & Co. 1997).

The technique uses a range of qualitative keywords to drive the allocation of degrees of significance and probable frequency of occurrence. The assessment covers a range of standards or impact areas which a release or activity might affect, from actual environmental impact to company reputation and compliance. The use of quantitative impact assessment techniques in this area has been limited, with a small amount of work carried out using mass balances in Germany and Denmark (Danish Steel Works 1995, Fecker 1992). However, in order to make the exercise manageable the above ranking approach is generally used.

2.3.2 External Investor Assessment Tools.

The assessment techniques used by potential investors have traditionally been based on qualitative company information. In contrast to the compliance driven internal assessment tools used by companies, the external use of company environmental information in making investment decisions has grown out from the ethical investment trusts established by companies such as Friends Provident and Jupiter Tyndall (see Holden Meehan 1997). The environmental part of their ethical investment criteria might include associations with defence industry clients or controversial developments. There would be no assessments of emissions or the possible impact of these emissions. A recent study by NPI has tried to move beyond these criteria, in an attempt to recognise the environmental projects and associations presently being undertaken by companies. NPI's Best in Class study aimed to identify the environmental leaders within a range of industrial sectors, based on positive qualitative criteria (NPI 1997).

More recent developments to inform such decisions have started to look at the presence of environmental policy statements, management systems and accreditation to standards as a way of assessing the environmental performance of a company (see BiE 1996). The results of the BiE study do, however, not look at the environmental burden associated with different companies, only assessing the presence of a variety of management systems and initiatives for improving environmental performance. The presence of these systems does not say anything about the performance (in terms of compliance or burden) of the company concerned.

One investment trust does presently use both environmental emission data, as well as an aggregated index, to assess companies for its Environmental Value Fund (Uni Storebrand 1996). The EVF uses a sustainability index composed of the categories: global warming, ozone depletion, material intensification, toxic intensification, energy intensity, water use, environmental liabilities and quality of environmental management. However, no data is available from the fund managers as to the aggregation methods used to derive the sustainability index. The index has been applied on a sector by sector basis, comparing companies to the sector average. Companies must score well above this average in order to participate. The approach is similar to the best in class study above and the philosophy behind the eco-label scheme. However, no limit as to the percentage of each sector that can participate has been set for the EVF. It is surprising that a sector specific approach has been taken, when an aggregated index should be applicable across industry, in contrast to the eco-label scheme, where an LCA approach has been used to help derive a set of product criteria for a range of product groups. In the context of sustainable development (traditional and physical) and investment in sustainable companies (see Introduction), the EVF needs to be made transparent, such that it can be applied to industry as a whole, thus excluding those with unacceptably high burdens. The EVF index does contain useful indicators of environmental burden, possibly derived from the LCA work discussed in section 2.2. However, from a purely environmental perspective, a number of qualitative categories have been included which could not be used as part of a generic index.

2.3.3 Internal Site Application Tools.

Integrated process assessment tools have only recently been used as part of the decision-making process for new site developments and site re-development. This has primarily been in response to the assessments of Best Available Techniques Not Entailing Excessive Cost (BATNEEC) and Best Practicable Environmental Option (BPEO), now required for processes subject to Integrated Pollution Control under the EPA 1990. This section will look at three tools presently used to carry out these assessments by the British Petroleum (BP) company, the Chemical Industries Association (CIA) and regulatory guidance proposed by Her Majesty's Inspectorate of Pollution (HMIP), now the Environment Agency.

(i) The BP ENVOP Technique.

The Environmental Optimisation (ENVOP) technique was developed by Costain Engineering in conjunction with BP as an improvement on the Hazard and Operability studies used in the past (Potter & Isalski 1993). The technique uses a review procedure rather than a formal aggregation method to derive an index. The technique is based upon a set of review meetings which follow the steps given in Figure 2.5.

Environmental objectives are used to target the review, with keywords being used to allocate actions. The options generated are then optimised using economic analysis to review the final set of prioritised recommendations. The environmental objectives set as part of the technique are based on mass emissions or threshold limits for vapour emissions, aqueous effluents, solids, utility stack gases, noise and odour. No aggregation methods are used within these categories to take account of the relative toxicity, for example, of the effluent or emissions.

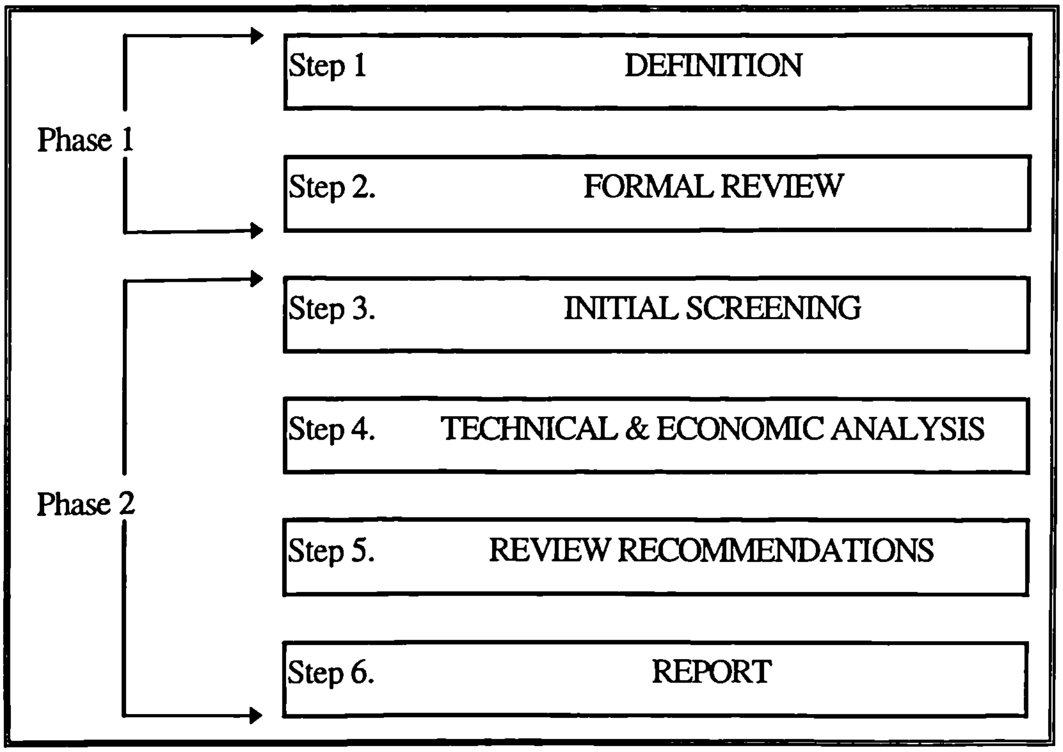


Figure 2.5 - BP ENVOP Assessment Procedure (Potter & Isalski 1993).

The technique, therefore, only optimises the financial data across the mass releases. In effect the method goes as far as stage 3 in the ERL (DTTI et al. 1993), and as such would not be able to contribute to a generic environmental performance index.

(ii) The CIA BPEO Assessment Methodology.

The second integrated process assessment tool available has been proposed by the Chemical Industries Association as an alternative to a methodology proposed by HMIP (1994). This on the grounds that there is no scientific basis for HMIP's method which expresses a variety of environmental effects as a single number (CIA 1995a).

The procedure suggested by the CIA is intended for chemical manufacture, but might also be applied to other manufacturing processes, especially where there are few practicable technical options.

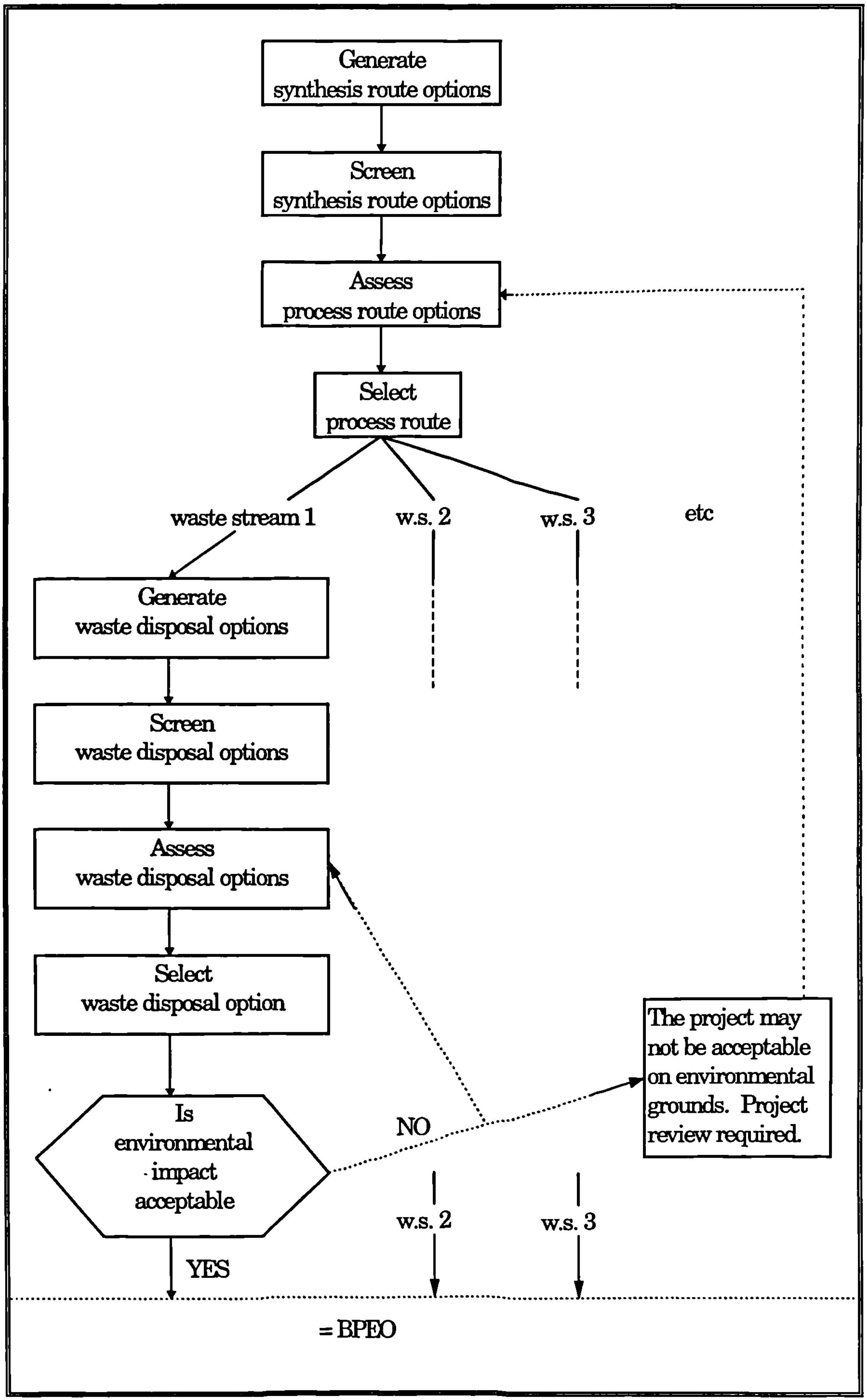


Figure 2.6 - CIA BPEO Assessment Procedure (from CIA 1995a).

The stages of the procedure are given in Figure 2.6. The procedure is made up of two distinct phases for which different assessment tools are used. The first covers the selection of process route options, and the second waste disposal options. The final selection is then checked to ascertain whether the impact is acceptable for BPEO.

The assessment of process route options uses a wide variety of decision parameters, of which an example has been given as part of the CIA discussion document (CIA 1995a). These include:

(a) Theoretical quantity of waste per unit of product.
(b) Forecast quantity of waste per unit of product.
(c) Number of recycle streams.
(d) Number of prescribed/toxicological substances handled
(e) Quantity of special or hazardous waste.
(f) Quantity of total organic carbon in effluent.
(g) Quantity of dissolved solids in effluent.
(h) Quantity of nitrogen in effluent.
(i) Quantity of phosphorus in effluent.
(j) Number of volatile organic compounds handled.
(k) Amount of energy consumed.
(l) Number of high risk unplanned releases.

Within each category the data for each process route option is ranked in ascending order. The ranked values for each process option are then summed across the categories to give a rank total for each option. These totals are then ranked in descending order to give a process option preference list.

Having chosen the preferred process route option, the waste treatment and disposal options for dealing with the process waste are assessed. The available options are compared with CIGNs for achievable release, followed by further studies using dispersion calculations for releases to air and water in the local environment. A final check of the process-waste option is then made to ensure that the releases meet all the environmental criteria for the site.

The methodology provides an interesting set of potential impact criteria for the assessment of the process route options. However, the majority of the impact categories are based on an unaggregated sum of mass emissions. These categories, in a similar way to the BP ENVOP technique, do not take account of the relative contributions of the constituent substances to the environmental problems they cause. For example, data on the number of VOCs and prescribed substances used is a very weak measure of the relative contributions of the different process route options to photo-chemical smog creation and toxicity. The ranking within each category will introduce large errors between options where the true potential contribution to a problem has not been calculated. Ranking the options across the categories is, however, an appropriate way of aggregating the data in the absence of physical weighting factors. This is also a problem for the LCA approach discussed above, where a number of potential impact categories have to be aggregated into one value.

The assessment approaches used for the waste management options are very site specific and would not, therefore, be able to contribute to a generic index. The approach used bears a strong resemblance to the BPEO assessment methodology below, for which it was designed as an alternative. However, the selection of waste management options from the dispersion studies is based on expert opinion, rather than a specific assessment methodology, such as the IEI (EA 1997a). The second phase of the CIA approach may, therefore, provide a potential site-specific assessment tool with which to compare a generic index.

(iii) The HMIP BPEO Assessment Methodology.

In April 1994 Her Majesty's Inspectorate of Pollution for England and Wales published a consultation document for an integrated process assessment tool called the BPEO assessment methodology for IPC processes (HMIP 1994). After consultation this methodology was adapted a number of times before being published as guidance in 1997 (EA 1997a). The following description focuses on the second draft of the approach (HMIP 1995a). The BPEO assessment methodology was designed for assessing different process options at sites subject to Integrated Pollution Control. The methodology is designed for use on a site-specific basis, including both an environmental and economic dimension to the assessment, similar to the above two approaches. This section looks only at the environmental dimension of the tool.

Environmental assessment tools are used as part of the methodology to:
(a) establish those releases exceeding the tolerable limits set.
(b) highlight those releases that are priority for control.
(c) determine those releases that are insignificant to warrant further study.
(d) predict the maximum concentrations of all significant releases.

The expected releases from the base case are firstly quantified. A process is not permitted to operate for which the Predicted Environmental Concentration (PEC) is greater than the Environmental Quality Standard (EQS) or Environmental Action Limit (EAL) for that substance in the medium to which it is released. The

PEC for a substance consists of the Process Contribution (PC) and ambient concentration for that substance. The EQSs used have been taken from specific UK and EU legislation on releases to the environment, whereas the EALs have been derived from occupational and other international standards, using a safety factor (see HMIP 1995a&b).

Insignificant releases are those which result in a PC less than 0.2% of the EQS or EAL for that release to a given medium. The PC for a substance corresponds to the location in air, water or on land that has the highest annual mean concentration or deposition rate for that substance. This corresponds to a release from the process only, excluding ambient concentrations. Limits are available for releases to air and water, and deposition on land either direct or as a result of a release to air. The significance limits have been calculated for all the substances covered using a simple algorithm which is dependent upon stack height for releases to air and river/estuary discharge for releases to water.

Substances that are priority for control are those for which:
(i) The PEC is greater than 80% of the EAL or EQS for that substance; or
(ii) The PC is greater than 2% of the EAL or EQS for that substance.

Alternative process options are then generated for the site and compared with a set of safety, cost and space criteria before moving onto the environmental assessment stage of the procedure.

During the assessment stage the releases from the base case and alternative process options are used to calculate the Integrated Environmental Index, the primary decision tool, as well as a series of additional environmental impact factors. The IEI is calculated from the Process Contributions for all significant releases from the process options.

The PCs are calculated under local conditions using recommended dispersion modelling techniques (Environmental Analysis Co-operative 1996) for releases to air, and riverine and estuarine waters. To calculate the IEI each PC is divided by its EQS or EAL to derive an Environmental Quotient (EQ) for the substance as shown in Equation 2.7.

Equation 2.7 - Calculation of the Environmental Quotient for a Substance.

$$EQ_{(S)} = \frac{PC_{(S)}}{EQS_{(S)} \text{ or } EAL_{(S)}},$$

where,

$EQ_{(S)}$ = Environmental Quotient for substance, S.
$PC_{(S)}$ = Process Contribution for substance, S.
$EQS_{(S)}$ = Environmental Quality Standard for substance, S.
$EAL_{(S)}$ = Environmental Action Limit for substance, S.

An Environmental Quotient is then calculated for each of the environmental media air, water and land by summing the EQs for all of the substances released to them, as shown in Equation 2.8. Substances released to air may also contribute to the EQ for land in the form of deposition from air.

Equation 2.8 - Calculation of the EQ for a Medium.

$$EQ_{(M)} = \sum_{1}^{n} EQ_{(S)},$$

where,

$EQ_{(M)}$ = Environmental Quotient for medium, M.
$EQ_{(S)}$ = Environmental Quotient for substance, S.
For all substances, S = 1 ...n.

The Integrated Environmental Index (IEI) is finally calculated by summing up the EQs for each of the media air, water and land, as shown in Equation 2.9.

Equation 2.9 - Calculation of the Integrated Environmental Index.

$$IEI = EQ_{(Air)} + EQ_{(Water)} + EQ_{(Land)}.$$

The IEI is used as the primary decision-making tool between process options, with additional input from a set of impact categories, covering:

(a) the short-term effects of releases to air.

(b) the global warming effects of the process.

(c) the contribution of the process to photo-chemical ozone creation.

(d) the toxicity potential of the waste generated by the process.

The first category is based on dispersion models for significant short-term releases. The remaining categories are calculated using mass emission data and impact factors which quantify the contribution of the emissions to the problems identified. The factors used to calculate these are similar to those used as part of the LCA methodology discussed earlier.

The environmental assessment methodology of HMIP provides a useful integrated site-specific environmental assessment tool in the form of the IEI. The additional categories introduce global and regional issues into the assessment, as well as an off-site issue, through the waste hazard potential, which should perhaps not be included as part of a site application decision. No guidance has been provided, however, on how to integrate these categories into the IEI. The Integrated Environmental Index quantifies the amount of available environmental capacity used for the substances covered by the methodology in relation to the environmental circumstances present at the site, taking account both of the rate of release of the substance, the movement of that substance in the local environment and the toxicity or impact of that substance. This is in contrast to the CIA methodology which does not use this approach when choosing the process options. Here a site-specific approach is only taken when deciding on the waste management and disposal options, but without a pre-determined system for deciding between the effects of different substances and between different media. Given the site-specificity of the IEI this approach would be very useful as a comparator for a generic index order to determine the significance in the capacity of environmental sites. The additional impact categories, which mirror the impact categories used in LCA, may be applicable to a generic indexing methodology.

2.3.4 Conclusion.

The use of process assessment techniques within companies presently varies depending on the nature of the assessment being undertaken. The techniques used vary from subjective ranking techniques as part of environmental management systems, to a variety of site-specific and generic impact assessment techniques used to assess different options as part of an IPC process development application. The use of simplistic techniques as part of EMSs contrasted strongly with the generic assessment models being developed by investment assessors, which rely on the mass emission data supplied by the EMS. If only the significant effects, based on this approach are reported then it is highly possible that certain key emissions made be excluded from the investor's assessment. However, the work on sector EPIs may prevent this happening (see European Green Table 1993). The process assessment tools used for a site application varied from a subjective approach by BP, through a mixture of a generic and site-specific approach from the CIA, to one intended solely to optimise the amount of environmental capacity used within the environment local to the process under development. This mixture of generic and site-specific assessment tools suggests there is no framework present within this field which dictates which approaches are best used where, and more importantly, why.

2.4 Perspective & Future.

The last two chapters have looked at the use of impact assessment techniques at a variety of levels, from the operation of a specific site to the reporting of environmental performance at intergovernmental level. The use of these assessment techniques has varied from highly qualitative and subjective to quantified objective approaches. Among the quantitative impact assessment techniques used these have taken the form of both site-specific and generic approaches. The basis for the use of the different approaches, however, has been clear in only two cases.

Firstly, the use of a variety of environmental performance indicators by intergovernmental organisations such as the United Nations has been supported by a data collection framework based on the Pressure-State-Response approach. This approach has also been adopted by the EU and the grouping of emissions into similar problem categories can also be discerned in a number of national environmental accounts. The PSR approach supports the principle that environmental capacity will differ from one area to another. To take account of this indicators of both pressure (the burden on the environment) and state (the extent to which that burden has been absorbed) are reported. The environmental burden data produced as part of these PSR reports are presently given as mass emissions, with no assessment of the potential impact using a level plane or generic assessment tool. However, potential methods that might be used within the problem categories covered in the reports have been suggested in a number of intergovernmental reports. These techniques, which have also been used in Life Cycle Assessment, may be useful as a generic assessment tool.

Secondly, an integrated site-specific impact assessment tool has been proposed by the Environment Agency for the selection of process options for processes putting in an IPC site application. This tool, the Integrated Environmental Index, is specifically intended for use on a site by site basis and models the releases of substances in the local environment.

Other tools proposed for this purpose combine both generic mass based assessment techniques with site-specific impact assessments. The rationale behind these, however, has not been defined, and in the case of the CIA process assessment tool does not recognise the different capacities of the local environment to absorb emissions to air and water, using a mass emission category approach to chose process options. This approach does not look at the relative contributions of the emissions to an environmental problem, either at a local or global scale.

The use of generic impact assessment approaches by companies in western Europe and North America has also been very sparse, with only Dow-Europe and ICI making an attempt to relate their emissions to a generic environment. Many of the companies, however, do produce mass emissions as part of their annual environmental reports. The rationale behind this has not been clearly defined, and does not appear to be based on a framework. A possible exception to this is the work done by the European Green Table, which puts forward a range of management and operational performance indicators for a number of industrial sectors. However, the different indicators proposed, with compliance indicators for management and mass emissions for operations, are not based on any principle which acknowledges the differences in the environmental capacity between sites. If management at a corporate level only looks at compliance, therefore, they may be getting the wrong picture of their company's environmental burden. There is also a limited potential for exploiting compliance indices in the future as many companies are now aiming for 100% compliance as part of the registration for environmental management and accounting standards. In examining the performance of a company, therefore, the environmental burden is the most precise measure of the overall environmental cost of the operation, while compliance indicators describe how much of the capacity available locally the company is using or how well the site is being managed. This capacity and the associated consents may vary from one location to another.

The use of impact assessment methodologies as part of the Life Cycle Assessment field also lacks a standard or agreed rationale, with different practitioners claiming that LCAs should be based on the sum of site-specific impact assessments for a product, as this reflects the true impact of a product whose components are produced at a wide range of sites. If this is not done then the results for product improvement will not be relevant to the site at which the product and its components are made. However, these site specific assessments introduce a site-dependent environmental variable into the assessment, as capacity may differ from one area to another. Where comparisons are being made of one material versus another for use within a single product, or on the relative environmental burdens between two similar products, this must be done on an environmental level plane, excluding those site-specific differences. Presently a two-track approach has been suggested by White et al. (1995), although this is more observation than rationale. If appropriate assessments are to be made the use of site-specific and generic tools needs to be differentiated, with site-based tools used for location studies and generic tools for environmental reporting and assessment. There appears to be a need, therefore, to test the potential differences between site-specific and generic impact assessment tools and ascertain whether site location does have a significant effect on site-specific assessment methods. By comparing a purely site-specific index, such as the IEI, with a generic index derived from the environmental themes approach used in LCA, the need for, and potential structure of, an assessment and reporting framework at a company level can be determined.

If a generic impact assessment were to be required at a company level this also affects the level at which LCAs should be carried out. At present the variability of emissions used for sectors in carrying out an LCA is not provided and many materials used at a site are excluded from the assessment. This suggests a need to establish at what level of detail the variability between processes within the same sector, as well as the variability of a single process becomes insignificant. If the differences between different companies within the same sector are large, then the use of a generic index at company level will provide an efficient way of providing information on the environmental burden associated with a product or material by the companies. If such burden data represented that for the whole life cycle of a product, as is the case with cost or price data, the boundary problems presently hindering many LCAs would be solved. Databases providing burden on a sector, which represents the lifecycle burden of the material produced rather than the production burdens of the sector, would be much more useful in informing product design strategies, again provided sector variability data is included.

To achieve this each process would have to undertake an assessment of their process using a "functioning unit", as opposed to a functional unit. This is one area that an LCA has not been designed to address. Even though a product may have been improved, the motive behind doing so will often be to increase sales, since companies need continued consumption and growth in order to achieve success (Gray et al. 1993). Even with a decrease in product burden, therefore, the total burden attributable to a company may remain the same or even increase due to increased sales and use of the product concerned. This issue of total burden used by a company and whether this is sustainable within a global or continental context has not been addressed adequately to date. If this kind of data was to form part of an environmental accounting system the environmental burdens associated with the materials used would be provided by suppliers and added into the emissions or impact data provided with the product or material. Having ascertained whether site-specific indices are affected by site location, it can then be determined if a generic or site-specific index might be used to manage a site or company as well as providing environmental information as part of an environmental accounting system. One of the critical factors influencing a company's ability to do this is data availability and accessibility.

This project aims to address these questions by examining the use of a physical site-specific index with a similar generic index to establish their appropriate area of use within a company context rather than across a product life cycle. This will be done by comparing the use of the EA's Integrated Environmental Index with a generic index derived from the environmental themes approach used in LCA at a series of companies within the UK. These indices exclude socio-economic factors as they do not quantify the actual limits or relationships within the physical environment on which each company's performance is being measured. Based on a limited number of companies the extent of variability between sites within the same sector will be examined, ending with a study of the accessibility to the data required.

By applying the indices to real-world sites the potential interchangeability of the IEI and the LCA index will be examined, as well as establishing the appropriate area of use of the two indices throughout the information life cycle of a process. The potential use of alternative assessment tools for process assessments under IPC has been suggested by Eduljee (1995), with the Environment Agency having recently carried out a conceptual study on the subject (EA 1997b). This study suggested that there was no basis for interchangeabliity, although this was not based on a quantitative comparison of the assessment tools. By using actual data this study should be able to determine a basis for the use of site-specific and generic assessment tools within an organisation, as well as providing some insight into their use at a higher level to inform product development and national policy on sustainable development. The rationale behind the indices used, the methodologies used within them, and the methods used to collect and assess the data for them will be discussed in the next chapter.

CHAPTER THREE

Methodology

The IEI and TEPI

3.1 Introduction.

This chapter sets out the principal aims of the project and the methods used to achieve them. The chapter starts with an explanation of the rationale behind the project, based on the findings in the previous two chapters, together with a set of assessment criteria that will be used to examine the potential use of site-specific and generic environmental performance indicators. The rationale is followed by the methods used to construct a generic environmental performance measure, the Total Environmental Potency Index - intended as a management tool -, and its comparator, the Integrated Environmental Index - a site application tool - (see Figure 3.1). The techniques and assumptions employed to calculate the indices are also set out. Thirdly, the procedures and assumptions used to find and collect data from the seven industrial collaborators on the project will be defined. These procedures form the basis for the data given in Chapters 4 to 10. Finally, the methods employed to analyse the outputs from the two indices will be explained. These form the basis for the results and discussion in Chapters 11 & 12.

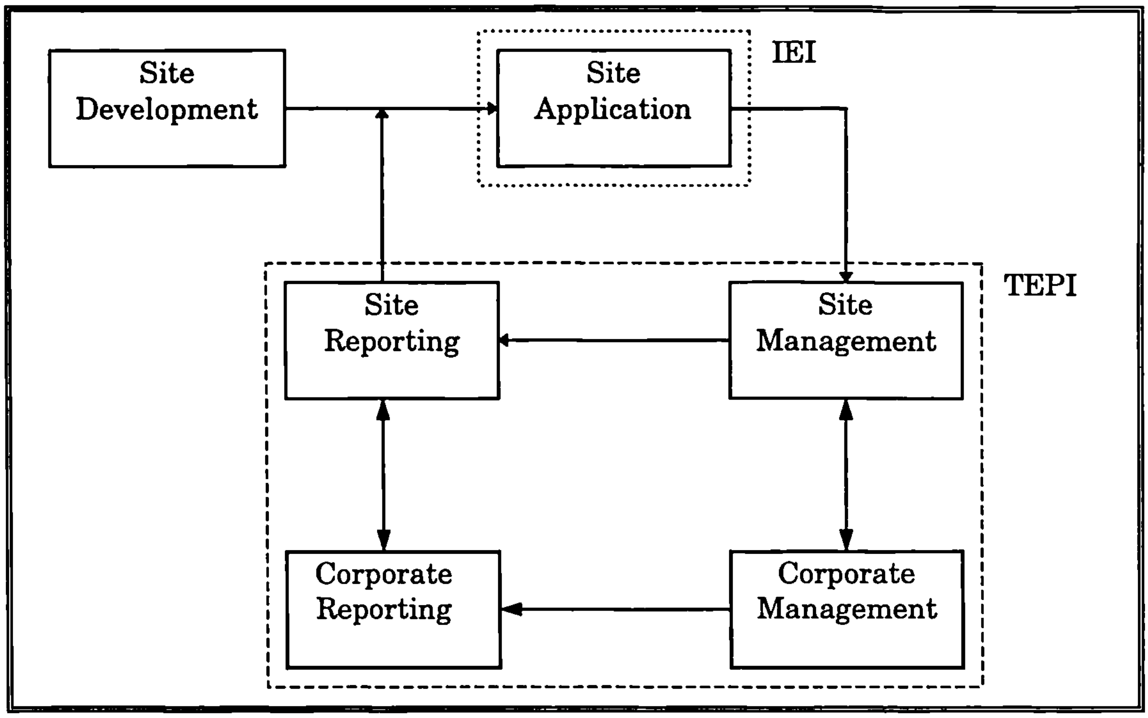


Figure 3.1 - The Process Information Life Cycle with IEI & TEPI.

3.2 Project Rationale.

The past two chapters have shown that there is a lack of rationale behind much of the data collected by organisations to manage and report on the performance of their operations and products. One exception to this is the approach taken by inter-governmental organisations reporting on the state of the environment. At a national and corporate level, with the exception of the environmental accounts for the Netherlands, the same is true, with no explicit rationale behind the compliance and mass emission based indicators used. It is unclear whether this is due to a lack of understanding of the environmental processes taking place in the environment, or whether data are provided solely on the basis of requests by outside users.

At a higher level, where impact assessments are used to examine products and material flows using LCA approaches, there is also a dichotomy between the use of site-specific and generic techniques to perform the same task. Both site-specific and generic impact assessment tools and process emission data are used to carry out similar studies.

These issues raise a number of questions which relate both to the use of indices at a site and corporate level within an organisation to manage its processes, and to the management and development of its products along their life cycle. The process related issues primarily concern the appropriate areas of use for site-specific and generic impact assessment tools. In addition to these the product issues also relate to the appropriate use of process-specific and generic emission data used as an input to an LCA.

(i) Site Variability.

In the absence of a framework for the use of site-specific and generic impact assessments for site or product management and development the primary question is, "Does site location significantly affect compliance based indices?" If the environmental capacities available at a range of sites differ to such an extent that they significantly affect the comparative results obtained from an assessment using a site-specific and generic index, then the two cannot be used interchangeably. The differences would also affect the appropriate area of use for the indices, both within and outwith a company or site (see Figure 3.1). With significant differences, companies assessed using compliance based indices could not be compared on a level plane. Data from a range of sites within an organisation would also not be comparable. A different tool, or generic index, would then be required for assessments at this level within and without an organisation, with site-specific indices used at the site level only. By examining the relationship between a site-specific and generic index, and the sensitivity of the two indices to similar emissions, the significance of site variability on these tools and their appropriate areas of use can be determined.

(ii) Sector Variability.

It is unclear whether the present use of sector average data by many LCA studies is valid, especially when choosing between alternative materials or accounting for the emissions of a supplier. This raises the question, "Does site-specific emission data from companies within the same sector differ significantly from the sector data available?" Large differences would mean that companies may be significantly under or over-estimating the environmental burden for their present supplier chain when using LCA databases. Material usage decisions made without variance data for a given sector may also be invalid, where the burdens from the lower and higher end of two materials overlap.

(iii) Process Variability.

Given a high amount of variability within an industrial sector it may be more appropriate for companies rather than industry associations to provide emission and/or impact assessment data. This data would be provided alongside traditional cost data, as part of an environmental accounting system. If this is to take place, an appropriate time-scale must be chosen for which to provide this data. This raises the question, "Do the present annual reports produced by companies adequately take account of the potential variability of the processes and emissions, despite the continuous nature of many industrial processes?" It may be more appropriate, for example, to provide monthly or weekly data corresponding to the batches and products manufactured. There may also be a limit to the level of detail that can physically be achieved, as well as the extent to which inherent variability can be controlled, for example, emissions from the reactor vessel of a chemical process. The potential differences in process variability between companies also raise the question, "Can this measure of process variability be used to measure environmental management performance?" This might be used to assess the effectiveness of management systems rather than the actual environmental burden of a company.

(iv) Data Accessibility.

If site-specific or generic indices are to be used more regularly by industry this raises the question, "How accessible is the data required to calculate these indices?" Much of the data required will not presently be measured as part of a company's consent. The accessibility of this data may vary from one sector or company to another, perhaps depending on the size of the organisation.

To answer the above questions a site-specific compliance based index will be compared with a generic index using real world data from a range of industrial sites. The Integrated Environmental Index will be used as a purely site-specific tool, with a generic environmental index, called the Total Environmental Potency Index, being constructed from the environmental themes approach used in LCA. This approach incorporates the generic categories found as part of other generic assessment techniques covered in Chapters 1 and 2.

3.3 The Integrated Environmental Index.

The site-specific index being used as comparator for the Total Environmental Potency Index is the Integrated Environmental Index (IEI). The IEI forms part of the UK government guidance on the BPEO assessment for processes under IPC. The IEI is the main decision tool within this methodology, as described in section 2.3. The additional assessment factors used as part of the methodology will not be included as part of this study.

The IEI is calculated using equations 2.7, 2.8 and 2.9 in section 2.3, for all significant point source releases from a process. The IEI presently does not include emissions from non-point sources such as fugitive releases, or emissions from internal transport or product distribution. The emission rates are firstly tested for significance, using a series of tables for releases to water and air. These provide release rate limits for a series of stack heights and river discharge rates. Any substance released above these significance limits, which correspond to 0.2% of the

EQS or EAL for that substance, must be assessed in more detail. It is unlikely that any of the sites will have a release above the EQS or EAL, as this should be ensured as part of the development application or consents for the sites. The significance limit of 0.2% has been put forward by Her Majesty's Inspectorate of Pollution (now Environment Agency) as a rule of thumb based on past experience rather than proven no effect limits.

For those substances released in significant quantities to air, riverine surface waters, and estuarine surface waters, the dispersion of the substance must be modelled within the local environment to calculate its Process Contribution (PC). This should be carried out using appropriate modelling techniques (see Environmental Analysis Co-operative 1996). No guidance is provided as to which specific tools should be used, however, providing the potential for disagreement between companies and their regulator. The models used represent those recommended or used by the local regulatory authority (SEPA or EA) to set consents, and have not been tested or calibrated for the sites concerned. The prime objective has been to simulate the circumstances which presently exist in applying the IEI.

3.3.1 Air Dispersion Modelling.

The dispersion of substances released from elevated point sources, such as chimneys and vents, will be examined using a three dimensional Gaussian dispersion model used by the USEPA (1992). The software is called the Industrial Source Complex Long Term (ISCLT) model, which calculates the locations with the maximum annual average concentration of pollutants in the air, as well as their deposition to land, from a range of point and area sources. The model is one of a number recommended for possible use by the Environment Agency and was used solely due to its availability. More recently a comparative validation of the different models has been carried out which may result in a specific model recommendation (see HMIP 1996). The IEI, however, presently only applies to elevated point sources. Emissions from other sources, such as leaks, safety valves and internal transport will not be modelled for the IEI.

3.3.1.1 The Industrial Source Complex Long Term (ISCLT) Model.

To calculate the dispersion of a pollutant from a stack the ISCLT model divides the area around the stack into twelve sections, each with an angular width of 30°. These twelve sections correspond to the number of wind direction categories for which meteorological data is available. The meteorological data used by the ISCLT model are called STAR summaries, which stands for STablility ARray. These summaries provide data on the frequency of occurrence of six wind speed and stability classes, within the twelve wind direction sectors N, NNE, ENE, E, ESE, SSE, S, SSW, WSW, W, WNW and NNW.

Using this data, together with data on the physical characteristics of the stack, the local climate, and the local topography, the quantity of substance released from the stack is then partitioned among the sectors according to the frequencies of wind speed and stability for each of the wind direction categories. The model calculates a series of vertical and horizontal concentration fields for the pollutant in each of the direction categories. An example of the resulting Gaussian plume used to this is given in Figure 3.2. The concentration fields calculated for each source are then translated to a common co-ordinate system, in this case a polar grid of elevation

Equation 3.1 - Calculation of Concentration along Guassian plume at X^1

$$\chi 1 = \frac{K}{\sqrt{2\pi} R \Delta\theta'} \sum_{i,j,k} QfSVD / u_s \sigma_z,$$

where,

K = Units Scaling Coefficient.
Q = Pollutant emission rate (mass per unit time).
f = frequency of occurrence of the ith wind speed category, the jth wind direction category, and the kth stability category.
$\Delta\theta'$ = sector width in radians.
R = radial distance from lateral virtual point sources (for building downwash) to the receptor $= \left[(x + x_y)^2 + y^2 \right]^{\frac{1}{2}}$
x = downwind distance from source centre to receptor, measured along plume axis.
y = lateral distance from the plume axis to the receptor.
x_y = lateral virtual distance.
s = a smoothing function.
μ_s = mean wind speed at stack height for the ith wind speed category and kth stability category.
σ_s = standard deviation of the vertical concentration distribution for the kth stability category.
V = the Vertical term for the ith wind-speed category and kth stability category.
D = the Decay term for the ith wind speed category and kth stability category.

heights at set distances from the source along each direction category, and summed to obtain the contribution to the location with the maximum concentration from all the sources (USEPA 1992). The annual average concentration at a point with respect to a single stack is calculated using Equation 3.1.

Input Data.

The data required for the model relate to both the local environment and the process being studied. Meteorological data is provided in the form of annual average STAR summaries for the nearest meteorological station for which such data is available. These are given in each separate chapter where the modelling results have been run. In addition to the quantity of each pollutant released, when

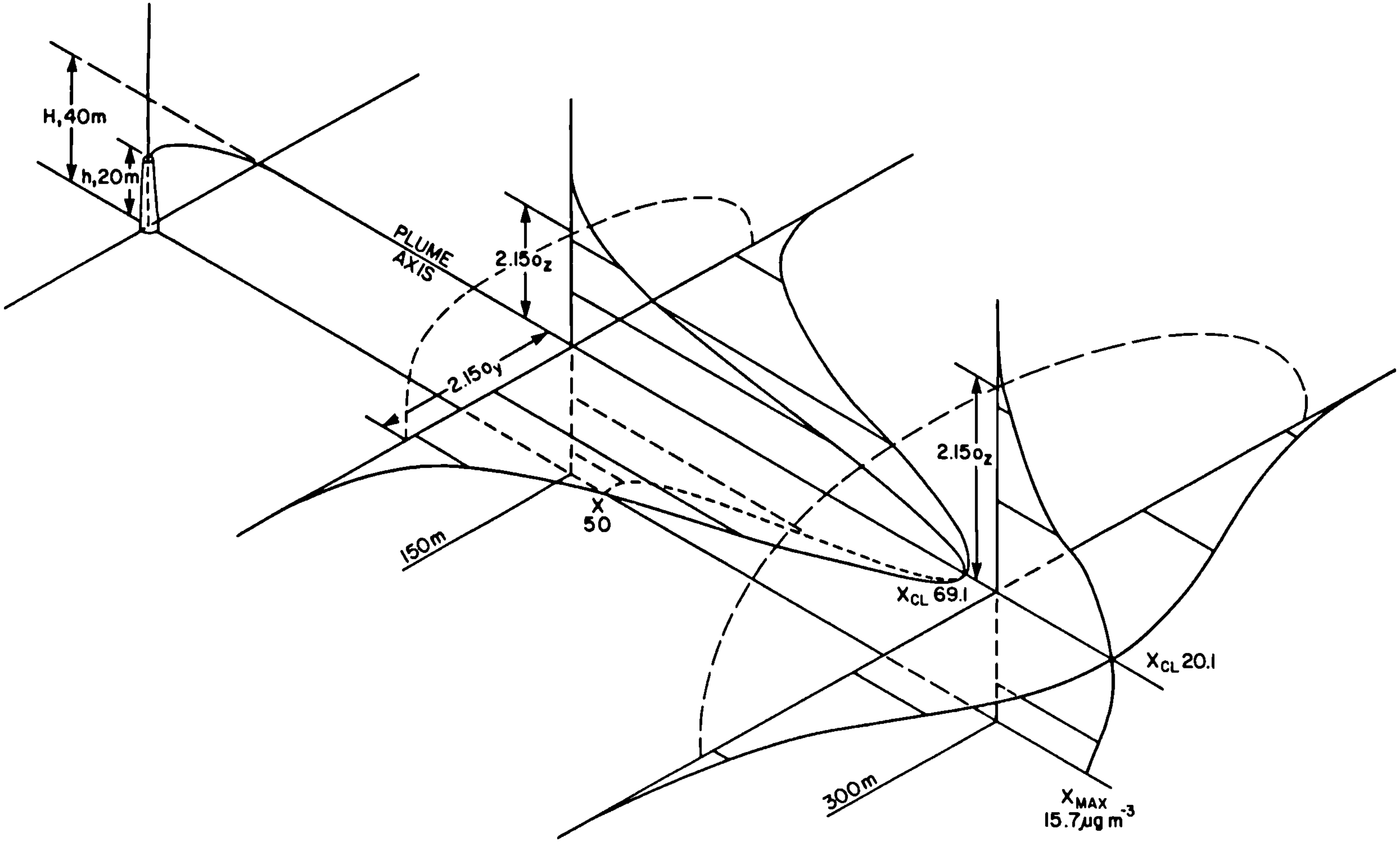


Figure 3.2 - Cross-section through a Gaussian Plume (Boubel et al. 1994)

deposition is being calculated, data on the settling velocity, mass fraction and surface reflection of the pollutant is required. In the absence of pollutant specific data, the recommended values given in Table 3.1 have been used (USEPA 1992). This assumes that all the pollutants are deposited in the same way, with no reflection back into the atmosphere from the surface.

Table 3.1 - Pollutant Characteristics used for Deposition Calculations.

Parameter	Value
Mass Fraction (one category only)	1.00
Settling Velocity (m/s)	0.01
Reflection coefficient	0.00

From USEPA (1992).

Site specific data, where available, is also required on the mixing depths of the stability classes, and the wind velocity categories, for which the STAR data has been collected. As this data was not readily available, the mixing depths recommended by Clarke (1979), have been used as a standard (see Table 3.2). In line with the generic nature of these parameters, an annual average temperature for Scotland of 8.9 C was used.

Table 3.2 - Stability Class Mixing Depths & Velocity Class Wind Speeds.

Stability Category	Typical mixing layer depth (m)	Wind Speed Category	Wind Speed (m/s)
A	1,300	1	0.8
B	900	2	1.0
C	850	3	2.4
D	800	4	4.3
E	400	5	6.7
F	100	6	12.5

From Clarke (1979).

Finally, a polar grid of elevation heights of the land surrounding the stack or group of stacks is required. The polar grid is set up along the radials for which the meteorological data has been provided, giving the elevation at a series of set distances from the stack or a reference point. Where a reference point is used the co-ordinates of the stack must also be expressed in relation to this point. This is usually done when emissions from more than one stack are being modelled. For a single stack the stack is given as the reference point.

Technical data is required to establish the height of the release and characterise the energy inherent in it. This energy will influence how far a given release is propelled in the local meteorological conditions. The site parameters required are:
(i) Pollutant emission rate,
(ii) Stack height,
(iii) Stack exit velocity,
(iv) Stack exit diameter,
(v) Stack exit temperature, and
(vi) Stack co-ordinates & elevation.

This data is supplied for each of the sites being studied, in Chapters 4-10.

The above parameters are combined with the local geo-meteorological data to produce predicted concentrations for the pollutant being studied at each of the points on the polar grid. The point with the highest concentration is used as the Process Contribution for the purposes of calculating the IEI, as described in section 2.3.

3.3.2 Riverine Surface Water Dispersion Modelling.

Significant releases to riverine surface waters have been modelled using a one-dimensional mass balance model, which uses a Monte-Carlo simulation to improve the validity of the results obtained. The model is presently used to set consents for the many riverine surface waters within the UK for which a dynamic multi-dimensional model would be too resource intensive.

The mass balance approach to calculating the river quality downstream of a discharge for riverine surface waters is based on the formula given in Equation 3.2 (from Warn & Brew 1980). Past methods have used this simple approach based on annual average discharge and quality parameters for the modelling of dispersion and the setting of discharge consents. However, work in this area by Warn & Brew (1980) has shown that this procedure is flawed, giving significant errors compared to the actual concentrations of a pollutant within the given river system. The above simplification is invalid as the distribution of the water quality downstream of the discharge depends on a combination of the upstream flow and quality distributions, which are not modelled by use of the above equation.

Equation 3.2 - River Quality Mass Balance Equation.

$$T = \frac{(FC + fc)}{(F + f)},$$

where,

T = Concentration of pollutant in river downstream of discharge.
F = River flow upstream of the discharge.
f = Flow of the discharge.
C = Concentration of pollutant in river upstream of discharge.
c = Concentration of pollutant in the discharge.

In response to this a more appropriate model has been put together by Warn & Brew, as part of the NRA, which uses the means and standard deviations for the parameters in Equation 3.2 to calculate a distribution of downstream concentrations, T.

The models used to calculate the PCs for those companies (D & E) discharging to riverine surface waters, are calculated depending on the relationship between the flow of the discharge and the river to which it is discharging. Where the discharge flow is linked to that of the river discharge, for example, at a sewage works which responds to rainfall in the same way as the river, the WARN-BREW tool is used (NRA 1995). This approach assumes that the variables follow a Log-Normal distribution, with a correlation between the river flow and the discharge flow. The variables are, however, assumed to be independent. For discharges that are not correlated to the river flow, and for flow distributions that do not have a Log-Normal distribution the NPCARLO tool can be used (NRA 1995). This allows any non-parametric distribution to be used for which it then calculates the resulting downstream water quality distribution. The data format required for each of the parameters to carry out the calculations in Equation 3.2 is given in Table 3.3.

Table 3.3 - Data format specification for Warn-Brew & NPCarlo (NRA 1995).

Parameter	Data format
River Flow	Mean and 5-percentile for Warn-Brew Flow Distribution Curve for NPCarlo
Upstream River Quality	Mean and standard deviation
Discharge flow	Mean and standard deviation
Discharge Quality	Mean and standard deviation, or Mean and 5-percentile

These parameters have been calculated for the relevant companies as part of the emission data given in Chapters 4-10. When using this data to calculate the PC as part of the IEI, the upstream river quality is entered as zero, as the PC excludes the ambient concentrations of the substance being modelled. The results obtained from the model give the mean annual concentration for the substance modelled from the distribution generated. This value will correspond to the location with the maximum concentration, which must be used as the PC, as discussed in section 2.3. The one dimensional approach used here assumes that the pollutant released is equally distributed and diluted across the whole width of the river at the point of discharge, for which the distribution is calculated. This point will, therefore, always correspond to the maximum concentration of the substance in the river. In practice, however, this does not take place. A release will result in an initially higher, more localised concentration, as the discharge and river water are mixed.

The model assumes that the equilibrium point of dilution will occur after a suitable mixing zone and that the mean annual concentration calculated is equal to the actual concentration at this point. A further limitation to the model is that it assumes there is no degradation of the substances released. The effects of any degradation products are, therefore, ignored.

3.3.3 Estuarine Surface Water Dispersion Modelling.

For those companies discharging to estuarine surface waters (C & G), a different mass balance model has been used. This model is similar to the mass balance model above, in principle, but includes additional parameters that take account of the influences of salinity on the dispersion of the substances discharged. The mass balance is a longitudinal one-dimensional model for a uniform estuary, based on work done by the Department of Ocean Sciences at the University of Wales, Bangor (Sherwin 1986). The model is presently used by the Scottish Environment Protection Agency to derive consents for its major estuaries. However, it will be replaced by a dynamic multi-dimensional dispersion model in the near future. As the model is not available as a software tool, the mass balance equations have been entered onto a spreadsheet for calculation. The model uses the annual average figures for the parameters required, with no analysis of their respective distributions, as carried out as part of the work by Warn & Brew (1980).

The formula used to calculate the expected maximum concentration of a conservative pollutant - i.e., one that does not decay - is given in Equation 3.3. This maximum concentration will occur at the discharge point of the substance, with concentrations upstream and downstream always being lower (Dyer 1973). This method, as above, assumes that the pollutant is equally diluted within the quantity of fresh water input to the system, as well as the salt water with which this is mixed. In practice this will only occur after a suitable mixing zone, for which the predicted concentrations are assumed to be valid.

Equation 3.3 - Estuary Quality Equation for Conservative Pollutants.

$$C_o = \frac{M}{Q} * f_o, \ \{f_o = S^1 - S_o / S^1\}.$$

where,

C_o = Concentration at discharge point.
M = Discharge rate for pollutant.
Q = Freshwater input.
f_o = Freshwater fraction at discharge point.
S^1 = Salinity of sea outside estuary mouth.
S_o = Salinity at discharge point.

Equation 3.3 calculates the expected concentration of the pollutant released in the fresh water input from the river. The dispersion of the pollutant is then related to the amount of saline water present at the point of discharge - i.e. the fresh water fraction. For a tidal cycle a volume of the salt/fresh-water mixture must escape which contains the same quantity of freshwater as the river flow (Dyer 1973). Therefore, the lower the freshwater fraction of the estuary, the greater the total volume of water available for dispersion and the lower the final concentration of the pollutant released.

To model the dispersion of non-conservative pollutants - i.e., those that decay once they have entered the estuary - a different formula is used to calculate the maximum concentration at the point of discharge, as shown in Equation 3.4. It introduces a decay time parameter, which is important for these pollutants, when released to an estuary. As the high mortality rate for bacteria released from wastewater treatment plants is comparable to the flushing time of an estuary, most of the pollutant will decay within the estuary, before being dispersed as part of a tidal cycle.

Equation 3.4 - Estuary Quality Equation for Non-Conservative Pollutants.

$$C_o = \frac{M}{Q\sqrt{1+\alpha}}, \quad \{\alpha = 4K/(u^2\tau), \ \& \ u = Q/A\}.$$

where,

C_o = Concentration at point of discharge.
M = Discharge rate for pollutant.
Q = Freshwater input.
K = Dispersion coefficient at discharge point
A = Cross-sectional area at discharge point.
τ = Decay time for pollutant released

The above equation will be used to calculate the process contribution for releases of BOD to the estuaries at companies C and G. The data on pollutant emissions and estuary characteristics required to calculate the pollutant concentrations at the discharge point using the above equations will be given in Chapters 6 and 10 respectively.

3.4 The Total Environmental Potency Index.

The Total Environmental Potency Index (TEPI), which is intended for use as a generic site/corporate environmental performance index (see Figure 3.1), has been derived from the impact assessment stage of the LCA techniques discussed in Chapter 2. The environmental themes approach was chosen as it represents the purest environmental form of generic characterisation available. Although the methodology used is presented as an assessment tool which examines environmental "issues", which might then be weighted using techniques from the social sciences, many of the characterisation factors used within the categories have been derived from a series of environmental system models or discrete chemical process algorithms. Consequently they represent good approximations to the real-world systems and physical relationships present. Many of these categories are also related in a physical sense, although these relationships have presently not been quantified.

The categories chosen were limited to those that represent a direct physical or toxicological effect within the biosphere or ecosystem of the earth. Two further categories, which do not have equivalency factors, were added to quantify a number of impacts not presently covered (see Table 3.4). Those categories which represent aesthetic or resource issues have been excluded. The resource issue covered, for example, by the biotic resources category has been incorporated into the land area category, which is the best surrogate measure of actual impact. The potential impact categories used have been called potency categories, to make a distinction between the potential impact of a product, which does not include the total burden or potency of all the products manufactured, and the burden of an organisation as a whole. The potency categories used to build up the TEPI, and the basis for the potency factors used within them are explained below.

Table 3.4 - Environmental Potency Categories & Factors used for TEPI.

Potency Category	Potency Factor	Reference Material
Greenhouse Effect	GWP	Global Warming Potential relative to CO_2 over 100 years (from IPCC 1994).
Ozone Depletion	ODP	Ozone Depletion Potential relative to Trichlorofluoromethane (from WMO 1994).
Human Toxicity	HTP	Human Toxicity Potential relative to 1,4-dichlorobenzene (from Guinee et al. 1996).
Aquatic Toxicity	AETP	Aquatic Eco-Toxicity Potential relative to 1,4-dichlorobenzene (from Guinee et al. 1996).
Terrestrial Toxicity	TETP	Terrestrial Eco-Toxicity Potential relative to 1,4-dichlorobenzene (from Guinee et al. 1996).
Ozone Creation	POCP	Photochemical Ozone Creation Potential relative to Ethylene (from Derwent et al. 1996).
Acidification	AP	Acidification Potential relative to SO_2 (from CML 1992a&b).
Nutrification	NP	Nutrification Potential relative to PO_4 (from CML 1992a&b).
Waste Heat	WH	GJ of Waste Heat lost to air and water from site.
Land Area	LA	m^2 of Land Area covered by site or used as biotic resources.

3.4.1 Environmental Potency Categories.

The categories chosen have been taken from those proposed by CML (Guinee et al. 1992a&b) as part of their product LCA tool (see Table 2.1). A number of the original CML factors have been excluded, or replaced with ones that better reflect the physical impacts from the categories proposed. Some of the categories have also been updated, following development work in the scientific field from which they were derived. The categories used, the characterisation factors within them, and the source of the factors are given in Table 3.4. All of these except land area have been taken directly from the CML list.

The categories for noise, odour, abiotic resources and victims have been excluded from the CML list. The first three do not constitute direct physical impacts on the environment, whereas occupational exposure and deaths can presently not be incorporated into an emission based assessment. Abiotic resources was included in the CML list as an environmental "issue", whereas odour and noise are aesthetic factors, which may be related to the psychological impacts on human carrying capacity in the future. The biotic resources category, which presently has no equivalency factors, has not been excluded from the CML list, but incorporated into the more generic land area category. This category and the remaining ones, are described below.

(i) Greenhouse Effect.

The potency category for the greenhouse effect measures the contribution of a range of gaseous emissions, released to the atmosphere, to the radiative forcing of the earth's climate. The potency factors for this work have recently been updated by the Intergovernmental Panel for Climate Change (IPPC 1994). The factors are

Table 3.5 - Potency Category Factors used for Emissions to Air.

Parameter Category	Acetone	Butyl Acetate	CF_4	Co	CO	CO_2	Cr	Cu	Ethyl Acetate	Heat
GWP	0	0	6,300	0	0	1	0	0	0	0
ODP	0	0	0	0	0	0	0	0	0	0
HTP	0	0	0	7,600	0	0	490,000	350	0	0
AETP	0	0	0	2.6	0	0	2.5	2.9	0	0
TETP	0	0	0	17,000	0	0	220,000	910,000	0	0
POCP	0.182	0.511	0	0	0.027	0	0	0	0.328	0
AP	0	0	0	0	0	0	0	0	0	0
NP	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	1
LA	0	0	0	0	0	0	0	0	0	0

Table 3.5 (contd.) - Potency Category Factors used for Emissions to Air.

Parameter Category	Iso-propanol	Methanol	Ni	N_2O	NOx	Pb	SO_2	V	Xylene	Zn
GWP	0	0	0	320	0	0	0	0	0	0
ODP	0	0	0	0	0	0	0	0	0	0
HTP	0	0	9,800	0	0.26	67,000	0.16	4,900	0	0.63
AETP	0	0	80	0	0	1.2	0	11	0	2.6
TETP	0	0	190,000	0	0	11,000	0	450,000	0	660,000
POCP	0.216	0.216	0	-0.427	0.028	0	0.048	0	0.9557	0
AP	0	0	0	0	0.7	0	1	0	0	0
NP	0	0	0	0	0.13	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0
LA	0	0	0	0	0	0	0	0	0	0

Table 3.6 - Potency Category Factors used for Emissions to Water.

Parameter	As	Cd	C_6H OH	Co	COD	Cr	Cu	Heat
Category								
GWP	0	0	0	0	0	0	0	0
ODP	0	0	0	0	0	0	0	0
HTP	51	130	0.89	31	0	9.3	1.1	0
AETP	190	4,500	720	88	0	84	96	0
TETP	0.0000097	0.025	34	0.0000002	0	0.000011	0.00001	0
POCP	0	0	0	0	0	0	0	0
AP	0	0	0	0	0	0	0	0
NP	0	0	0	0	0.022	0	0	0
WH	0	0	0	0	0	0	0	1
LA	0	0	0	0	0	0	0	0

Table 3.6 (contd.) - Potency Category Factors used for Emissions to Water.

Parameter	Hg	N	NH_{4+}	Ni	P	Pb	PO_{4-}	V	Zn
Category									
GWP	0	0	0	0	0	0	0	0	0
ODP	0	0	0	0	0	0	0	0	0
HTP	18,000	0	14	63	0	260	0	19	0.058
AETP	130,000	0	0	2,700	0	40	0	380	86
TETP	8,200,000	0	0	0.000031	0	0.0000002	0	0.000034	0.000025
POCP	0	0	0	0	0	0	0	0	0
AP	0	0	0	0	0	0	0	0	0
NP	0	0.42	0.33	0	3.06	0	1	0	0
WH	0	0	0	0	0	0	0	0	0
LA	0	0	0	0	0	0	0	0	0

Table 3.7 - Potency Category Factors used for Emissions to Land.

Parameter Category	Land Area
GWP	0
ODP	0
HTP	0
AETP	0
TETP	0
POCP	0
AP	0
NP	0
WH	0
LA	1

based on the modelling work done to predict the climate change likely for a range of emission scenarios. The category total has been calculated using the Global Warming Potentials (GWP) from this work, as shown in Equation 3.5. Those substances covered by the potency factors are shown, for releases to air, in Table 3.5.

Equation 3.5 - Calculation of Category Total for the Greenhouse Effect.

$$GWP_{Total} = \sum_{1}^{n} GWP_i * Q_i,$$

where,

GWP_{TOTAL} = Category total for the greenhouse effect.
GWP_i = Global Warming Potential of substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

(ii) Ozone Depletion.

The potency factors for ozone depletion have also been updated since their first publication as part of the CML approach (Guinee et al. 1992a&b). The technique is identical to that above, calculating the potential for a range of gases emitted to air to contribute to the degradation of stratospheric ozone. The revised figures have been produced by the World Meteorological Organisation (WMO 1994) as part of its ongoing assessment of ozone depletion. The category total has been calculated using the Ozone Depletion Potentials (ODP), as shown in Equation 3.6.

Equation 3.6 - Calculation of the Category Total for Ozone Depletion.

$$ODP_{Total} = \sum_{1}^{n} ODP_i * Q_i,$$

where,

ODP$_{TOTAL}$ = Category total for ozone depletion.
ODP$_i$ = Ozone Depletion Potential of substance, i.
Q$_i$ = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

Those substances released for which potency factors are available are shown in Table 3.5 for releases to air.

(iii) Human, Aquatic & Terrestrial Toxicity.

The potency factors for human, aquatic and terrestrial toxicity have all been updated from the CML work (Guinee et al. 1992a&b). The original work calculated a set of provisional human toxicity potentials, and aquatic and terrestrial eco-toxicity potentials, based on direct emissions to air, water and soil. An advancement on this work has recently been made by the Ministry of Housing, Spatial Planning and Environment (VROM) in the Netherlands (Guinee et al. 1996). The publication provides a set of potency factors based on the distribution of the release within a unit world, representing the physical characteristics of Western Europe, for a release to any of the media air, surface water, generic soil, agricultural soil, and industrial soil. The calculations have been carried out using a multi-media model called the Uniform System for the Evaluation of Substances (USES 1.0), developed by RIVM et al (1994). The distribution of the releases within the environment is calculated using factors for each of the chemicals covered on their mobility, degradation, and bio-accumulation. The results from the modelling studies are converted into toxicity potentials by relating them to a reference substance, namely dichlorosilane.

Equation 3.7 - Calculation of Category Total for Human Toxicity.

$$HTP_{Total} = \sum_{1}^{n} HTP_i * Q_i,$$

where,

HTP_{TOTAL} = Category total for human toxicity.
HTP_i = Human Toxicity Potential of substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

Equation 3.8 - Calculation of Category Total for Aquatic Toxicity.

$$AETP_{Total} = \sum_{1}^{n} AETP_i * Q_i,$$

where,

$AETP_{TOTAL}$ = Category total for aquatic toxicity.
$AETP_i$ = Aquatic Eco-Toxicity Potential of substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

Equation 3.9 - Calculation of Category Total for Terrestrial Toxicity.

$$TETP_{Total} = \sum_{1}^{n} TETP_i * Q_i,$$

where,

$TETP_{TOTAL}$ = Category total for terrestrial toxicity.
$TETP_i$ = Terrestrial Eco-Toxicity Potential of substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

The resulting Human Toxicity Potentials (HTP), Aquatic Eco-Toxicity Potentials (AETP) and Terrestrial Eco-Toxicity Potentials (TETP) are used to calculate the category totals for human, aquatic and terrestrial toxicity, as shown in Equation 3.7, Equation 3.8, and Equation 3.9 respectively. Those substances released by the industrial sites which are covered by the VROM factors are given in Table 3.5 and Table 3.6 for releases to air and water respectively.

(iv) Ozone Creation.

The ozone creation potency category calculates the contribution of a range of Volatile Organic Compounds (VOCs) to the formation of tropospheric ozone, relative to a reference substance, in this case ethylene. This work was originally performed by the United Nations - Economic Commission for Europe (UNECE 1991) and used as part of the CML list. The work has since been updated by Derwent et al. (1996). The factors were derived from a North-West European model for ozone formation in the UK. The results from this work, therefore, represent a less generic characterisation method, although it does exclude site-specific differences which might otherwise affect the results. The category total is calculated using the Photochemical Ozone Creation Potentials (POCP) for the relevant substances released, as shown in Equation 3.10.

Equation 3.10 - Calculation of Category Totals for Ozone Creation.

$$POCP_{Total} = \sum_{1}^{n} POCP_i * Q_i,$$

where,

$POCP_{TOTAL}$ = Category total for ozone creation.
$POCP_i$ = Photochemical Ozone Creation Potential of substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

Those substances covered by the above work, and their potency factors are given in Table 3.5 for releases to air.

(v) Acidification.

The potency category for acidification measures the potential of a range of substances released to air to produce hydrogen ions, relative to a reference substance, in this case sulphur dioxide. The category total is calculated using the Acidification Potentials (AP) for the relevant substances, according to Equation 3.11. The potency factors used as part of the project are given in Table 3.5 for releases to air.

Equation 3.11 - Calculation of Category Total for Acidification.

$$AP_{Total} = \sum_{1}^{n} AP_i * Q_i,$$

where,

AP_{TOTAL} = Category total for acidification.
AP_i = Acidification Potential of substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

(vi) Nutrification.

The nutrification potency category measures the contribution of a range of nutrients, emitted to air and water, to the formation of biomass and the resulting oxygen demand from its degradation (see Guinee et al. 1992a&b). The calculations use the average composition of algae, $C_{106}H_{263}O_{110}N_{16}P$. The relative contribution to algae formation, of each of a range of nitrogen and phosphorus containing emissions have been calculated, assuming the supply of other nutrients is unlimited. The amount of oxygen required for the degradation of the algae is then related to the amount required for a reference substance, in this case phosphate (PO_4^{3-}). This is called the Nutrification Potential (NP) of that emission.

Equation 3.12 - Calculation of Category Total for Nutrification.

$$NP_{Total} = \sum_{1}^{n} NP_i * Q_i,$$

where,

NP_{TOTAL} = Category total for nutrification.
NP_i = Nutrification Potential for substance, i.
Q_i = Quantity of substance, i, released in kg.
For all substances, i = 1 ...n.

The NPs are used to calculate the category total for nutrification, as shown in Equation 3.12. The potency factors for those substances contributing to the category are shown in Table 3.5 and Table 3.6 for emissions to air and water respectively.

(vii) Waste Heat.

The waste heat category measures the potential contribution of the site to global climate change or aquatic temperature change. As these factors can presently not be included in the potency categories for the greenhouse effect or aquatic toxicity, the waste heat category from the CML list, which only includes aquatic waste heat, has been supplemented with heat lost to air from a site. For many of the industries taking part heat losses to air may also affect terrestrial flora and fauna, either directly, or through changes in local climate. The unit of measure has been changed to GJ of energy lost, as this provides the best relative contribution to the problem from the range of industries taking part. Each type of heat loss will have a potency factor of 1, as shown in Equation 3.13.

Equation 3.13 - Calculation of Category Total for Waste Heat.

$$WH_{Total} = E_A + E_W,$$

where,

WH_{TOTAL} = Category total for waste heat.
E_A = Energy lost to air.
E_W = Energy lost to water.

The potency factors for those substances contributing to the category are shown in Table 3.5 and Table 3.6 for emissions to air and water respectively.

(viii) Land Area.

The potency category for land area measures the potential contribution of the site to land use and direct damage to terrestrial flora and fauna. The category has been altered from the CML list to the area covered by a site in m^2 only, excluding the amount of time for which it is used. It now also includes the land area of any biotic resources utilised as land area is the driving factor behind most of these resources and their sustainability. Each vegetation type will require a minimum area of land in order to exist sustainably and support its respective fauna in a similar way. This land area can then be linked to the amount available in an area or nation to determine the remaining quantity that can be used for development and agriculture. The land area covered by an industrial site will affect this limit directly, more often than not resulting in the complete cessation of biotic life over this area. In the absence of potency factors to relate different types and qualities of land area to one another the total area covered or used by a process will be measured, with each land use area having a potency factor of 1, as shown in Equation 3.14.

Equation 3.14 - Calculation of Category Total for Land Area.

$$LA_{Total} = LA_S + \sum_{1}^{n} LA_i,$$

where,

LA_{TOTAL} = Category total for land area.
LA_S = Land area covered by site, s.
LA_i = Land area covered by biotic resource type, i, used. For all biotic resource types, i = 1 ...n.

The potency factors for those substances contributing to the category are shown in Table 3.7.

3.4.2 The Total Environmental Potency Index

The potency categories brought together to derive the TEPI form a collection of generic and regional potential impact categories, which operate at a number of different levels of detail and impact (see Chapter 2 and Chapter 12). The outputs from many of the categories can also be related to the input of some of the other categories, although the physical relationships between the two have presently not been quantified. In the absence of such relationships the categories have been combined into a single index using an additive approach to give the Total Environmental Potency Index, as shown in Equation 3.15.

Equation 3.15 - Calculation of the Total Environmental Potency Index (TEPI).

$$TEPI = \sum \{WH + LA + AP + NP + POCP + HTP + AETP + TETP + ODP + GWP\}_{Total}$$

3.5 Industrial Collaborators.

The emission data used to calculate the IEI and TEPI was derived from the sites of seven industrial collaborators in England and Scotland. The data used represents a mixture of both sampled and internally estimated emission data, as well as estimates calculated as part of the project.

Potential participants were identified from business directories, concentrating on those sectors most likely to have a range of emissions. Approaches were made to seventy companies from the chemicals, paper, glass, food & drink, textiles, micro-electronics, oil & gas and utility sectors by letter and telephone. From the ten positive replies received seven participants were chosen based on:

(i) The presence of a reasonable amount of freely available emission data for the site.

(ii) Access to material or energy usage data, to estimate emissions for which no data was available.

(iii) Interest and mutual benefit.

(iv) Openness.

Once agreement had been gained, the level of detail at which the site would be studied was decided. In general, those companies for which a large amount of data was available did not wish to participate at any level of detail, supplying the data available directly. These are referred to as black box sites. Those for which a large amount of the emissions had to be estimated participated as grey box sites. Here the site has been split down into a set of manageable sub-systems, for which material usage data was available. These sub-systems were then used to model the working of the site as a whole. The industrial sectors taking part, together with the level of detail at which the site was studied are given in Table 3.8.

Table 3.8 - Participating Company Sectors.

Company	Sector	Detail
A	Power Generation	Grey Box
B	Heat and Power Generation	Black Box
C	Paper Manufacture	Grey Box
D	Paper Manufacture	Grey Box
E	Micro-Electronics Manufacture	Black Box
F	Textile Manufacture	Black Box
G	Food Products Manufacture	Grey Box

3.6 Data Collection.

The data gathering exercise followed a pattern similar to that described in the inventory stage of an LCA.

3.6.1 Scope & Boundaries.

The process unit for which emission data was collected or calculated was defined as, "All operations relating directly to the primary process, up to the boundary fence for the participating site, and the distribution of the product from the process to a client, customer or agent." Indirect emissions, from the administrative, catering and engineering support services present on a site, will be excluded where these can be separated from the site total. For example, the use of electricity by administrative support would not be excluded where it is metered at one point, but discharges to sewer by a canteen would be excluded where these are separate from the process waste effluent. The period of operation for which data has been collected represents the year beginning July 1994 to June 1995 inclusive. Within this period the data was collected at monthly intervals.

The boundaries chosen for the data gathering exercise were intended to represent a standard sub-division of the process and distribution functions, which would allow a set of separate process assessments to be brought together into a complete life cycle for a product, without excluding any distribution functions. The responsibility or ownership of this function can vary from one company to another. In splitting up the process units of a life cycle the provision of service was used to define which process inherits the emissions from a distribution function. The process providing the service inherits the distribution emissions between it and its client or customer, irrespective of who performs the function or pays for it. This means that waste contractors inherit the transport emissions associated with the movement of material to their process, where this may not always be their responsibility in practice.

3.6.2 Initial Site Visit.

The data gathering part of the study was initiated with a site visit at which the primary processes taking place, the main materials used, and emissions released were discussed during a tour with the technical or environmental manager of the site. This information was then used to build up an initial black or grey box material and energy flow diagram for the site. This diagram was used as a basis for further discussions to establish:

(i) The availability of emission data for the site process and distribution of its products.

(ii) The availability of material and energy usage data, to estimate emissions from the site. Sector process emission factors will be used for black-box sites, with mass balance models for grey box sites.

(iii) An accurate material flow model for grey box sites with subsystems for which material flow data is available on a monthly basis.

(iv) A data gathering strategy with the grey box sites and agree data provision by the black box companies, together with a commitment of resources and time. For grey box sites this usually entailed agreed access to technical and administrative accounts and staff over a finite period of time varying between two to four weeks.

Having constructed a final material and energy flow diagram for each site the emission data available was collected from each site, together with the material usage data required for the emission factors used for the black box sites. The factors used to estimate emissions from these sites are provided as part of the individual site descriptions in Chapters 4 to 10.

3.6.3 Mass Balance Studies.

For those companies taking part as grey box sites, a large number of parameters covered by both the TEPI and IEI were not measured or calculated on a regular basis. This was especially true for emissions of trace substances contained in the treated effluent discharged. In order to estimate these emissions a mass balance was constructed for each of the sites and its sub-systems. This work differs from the emission factors used to estimate, for example, air emissions using factors based on stack samples or fuel constituents per unit of fuel used. As the materials are used at the sites in varying degrees to manufacture the products, the majority of the materials leave the sites as product, rather than waste.

In order to estimate these emissions from the sites a series of mass balances have been built up for those materials used in making the product. The mass balance uses information from the Material Safety Data Sheets (MSDS), which provide data on the principal substances in each of the products used at the sites. This data is entered onto a spreadsheet, in which the chemical constituents for each product are listed separately, multiplied by the quantity of each product used and summed across all the products used. The products are broken down into their percentage by weight of:

(i) specific chemical constituents,

(ii) water, and

(iii) unknown constituents.

The data on the quantity of unknown constituents will be used to assess the potential significance of inaccessible emission data from the MSDSs.

The chemical species specific input data for the site calculated from the MSDSs cannot be used directly to estimate emissions as has been done for fuel combustion emissions. As the materials pass through a series of processes which displace material for inclusion in the final product, or removal from the effluent stream, a series of removal factors have been used to estimate the amount of material removed. These factors can differ depending on where and for what purpose products are used within the process. Information on these factors has been built up from the material flow charts constructed for the sites. The factors applied have been calculated separately for each of the relevant sites, as shown in Chapters 4 to 10.

3.7 Data Analysis.

3.7.1 Site Differences.

To establish the relationship between the actual values of the two indices and ascertain whether they might be used interchangeably, the index values will be compared graphically and assessed for independence and sensitivity to change.

The use of graphical representation of the indices will help to establish the effect of site location on the results obtained from the IEI, and how these affect its relationship with the TEPI. This will be backed up using the correlation coefficient and a test for independence between the two indices. As the two indices operate at very different orders of magnitude and different input variables are used to calculate them, it may be more appropriate to analyse the ranked rather than the actual values. This is carried out using Spearman's Rho test for independence (Iman & Conover 1989).

Equation 3.16 - Calculation of the Test Statistic for Spearman's Rho.

$$\text{Test Statistic, } T_R = r_R\sqrt{\frac{n-2}{1-r_R^2}},$$

where,

$$r_R = \frac{\sum R_{X_i} R_{Y_i} - C}{\sqrt{\left(\sum R_{X_i}^2 - C\right)\left(\sum R_{Y_i}^2 - C\right)}}, \quad C = \frac{n(n+1)^2}{4}, \text{ and}$$

R_{X_i} represents the ranks of the X's from 1 to n (IEI).

R_{Y_i} represents the ranks of the Y's from 1 to n (TEPI).

The null hypothesis for the test is,

H_0 = IEI and TEPI are independent.

Spearman's Rho uses the Students t distribution with n-2 degrees of freedom, with the test statistic shown in Equation 3.16.

This test is also carried out using an alternative ranking system for the TEPI. As the additive approach used in the TEPI may be causing certain categories to override the index, the category totals within the TEPI have been ranked in ascending order for each month. The category ranks obtained are then summed across the categories for each month to give a total monthly score. These scores are finally ranked in descending order for input to the Spearman's Rho.

The sensitivity of the two indices will be tested to establish whether the IEI and TEPI respond to the same parameters. The results will also be used to establish whether this is due to site differences or inconsistencies within the indices themselves. The sensitivity will only be examined on a site by site basis. For the IEI the percentage increase in the IEI for a 5, 10 and 50% increase in the release of each parameter will be calculated. This step-wise approach has been used to take account of any parameters that may become significant only after larger increases. The TEPI will only be assessed for a 50% increase in each parameters. To back up the results obtained, the average change across each of the categories will also be calculated for a 50% increase in each parameter. The results obtained will be presented graphically using bar charts.

Finally, to establish whether the TEPI values might be used as a site application tool, the ranked index values will be compared to the IEI, using the correlation coefficient, r. As for the index values this will take place using both the TEPI and the ranked categories.

3.7.2 Sector Variability.

The differences in the environmental burden of processes within the same sector will be examined using environmental emission data for a number of substances which are available for all of the sites concerned. This will be carried out for the paper manufacture and power generation sectors taking part in the study. Emission data for the paper sector will be compared to that available for the sector from LCA databases to establish whether they differ significantly from the averages quoted. Emissions from the sites within the power generation sector will be compared to those from LCA databases as well as a number of electricity generation companies within the UK. This may show not only differences between the sites and the averages used by LCA studies, but also differences between the portfolios of companies which supply electricity to the sites taking part. As no variance data is available from the LCA databases, the results will be compared graphically. The coefficient of variation across the data sources given will be used to quantify the variability between the participating companies and the sector data available.

The potential differences between the power companies within the UK will be studied further to establish the environmental significance of the electricity used at each of the participating sites and the effect of changing the supplier. In order to do this the TEPI was calculated for the UK average generation mix, Scottish Power (SP) and Scottish Hydro-Electric (SHE) using emission data from an ETSU study (Bates 1995) on the power sector and the environmental reports of the two Scottish generators (Scottish Power 1995, Scottish Hydro-Electric 1995). The emissions from which the TEPI was derived are given in Table 3.9. The data given for the two Scottish generators includes contributions from Scottish Nuclear (1995), and sales between the two companies. Exchanges with the National Grid are excluded.

Table 3.9 - Emissions for the UK Average, SP and SHE (g/KWh).

Parameter / Generator	UK Average	Scottish Power	Scottish Hydro-Electric
CO_2	596.41	303.02	446.81
SO_X	2.55	2.46	5.05
NO_X	1.90	0.76	1.34
CH_4	2.04	0.00	0.00
N_2O	0.014	0.00	0.00
VOC	0.055	0.00	0.00
CO	0.091	0.00	0.00
HCl	0.000	0.023	0.052
Waste Heat (GJ/KWh)	0.0072	0.0043	0.0060
Land Area (m^2/KWh)	0.00037	0.000052	0.00011

Using the TEPI, the percentage contribution to the total environmental burden of each company was calculated using the UK average generation mix. This quantifies the relative importance of electricity use at the different sites. The percentage change in each site's TEPI was then calculated for a change to Scottish Power and Scottish Hydro-Electric. In addition to the TEPI, the average change across the TEPI categories was also calculated. The results are presented graphically, using bar charts.

3.7.3 Process Variability.

To examine the appropriateness of the time-scale used to assess the companies taking part, the variability in the environmental burden will be assessed. If the variability on a monthly basis is very high there may be a case for reporting on environmental performance on a weekly basis. However, if the continuous nature of many of the sites taking part results in a low variability over the year there may be a case for quarterly or annual assessments. Where there is a large difference between the amount of variability at companies within the same sector the potential cause of this will be examined. This may allow variability to be used as a measure of the quality of environmental management at the site, for use at a corporate level.

To allow comparison from one company to another, the coefficient of variation will be used as a measure of variability, with a CV of 5% set as a significance level, a low variability of 5-35%, a moderate variability of 35-65%, and a high variability above 65%. This will be carried out using both indices, with the average variation across the TEPI categories being calculated to back up the TEPI result obtained. The results will be presented graphically using bar charts.

3.7.4 Data Accessibility

To ascertain how easy it might be for the participating sites to use the IEI and TEPI on a regular basis, the accessibility of the data required for each of the sites will be assessed. This assessment will be based on the mass of the material and energy flowing into and out of the site systems at each company, as well as the number of parameters covered by each of the indices.

The accessibility of the data will be assessed using four levels:

(1) High = Data which is published in an external report such as an Annual Report or a Environment Report.

(2) Moderate = Data which is available from internal management and operations reports.

(3) Low = Data which is only available on separate documents such as invoices and daily usage/production lists.

(4) Inferred = Data which has been estimated or inferred from other material or energy usage data.

Where emission data has been inferred from material usage data and MSDSs, the availability of this data will also be assessed. This will be based on the percentage and mass of material which could not be determined from the MSDSs - i.e., that which was classified as unknown as part of the mass balance studies (see section 3.6.3). The data will be examined using stacked bar charts for each of the companies concerned.

3.8 Conclusion.

The above approaches to collecting and estimating emission data, and calculating the environmental indices, have been applied at each of the sites over the next eight chapters. The results obtained from the indices are then analysed in Chapter 11. The consequences of these results for the future use of the two indices are finally discussed in Chapter 12.

CHAPTER FOUR

Company A

Power

4.1 The Company.

Company A is a power generation plant taking part as a grey box site. The site is owned and operated by a UK public electricity company. The plant is fossil fuel fired, burning both oil and gas. It is subject to IPC and has emission limits set under the IPC Directive. The parent company has achieved BS7750 and produces an annual environmental report, which is publicly available. The site employs 160 people, from a total of 3,500 within the organisation as a whole. Environmental management is ultimately the responsibility of the site manager, being implemented by an environmental manager.

4.2 The Power Generation Processes and Emissions.

The power generation process has been divided into four sub-systems to help gather data and estimate emissions. These are: steam generation; electricity generation; cooling; and distribution (see Figure 4.1). The processes and emissions associated with these sub-systems are discussed below.

4.2.1 Steam Generation.

The steam generation system converts the energy available in the fuels into steam by heating water in two boiler sets, using gas and heavy fuel oil. Particulates are removed from the flue gases using cyclones, when oil is burnt. Demineralised townswater is used to generate the steam. An ion-exchange resin demineralises the water and is regenerated with sulphuric acid and caustic soda. Steam is generated in three cycles, providing high, intermediate and low pressure steam to the turbines in power generation. Condensate, returned from the cooling system, is supplemented with demineralised water to replace blowdown losses.

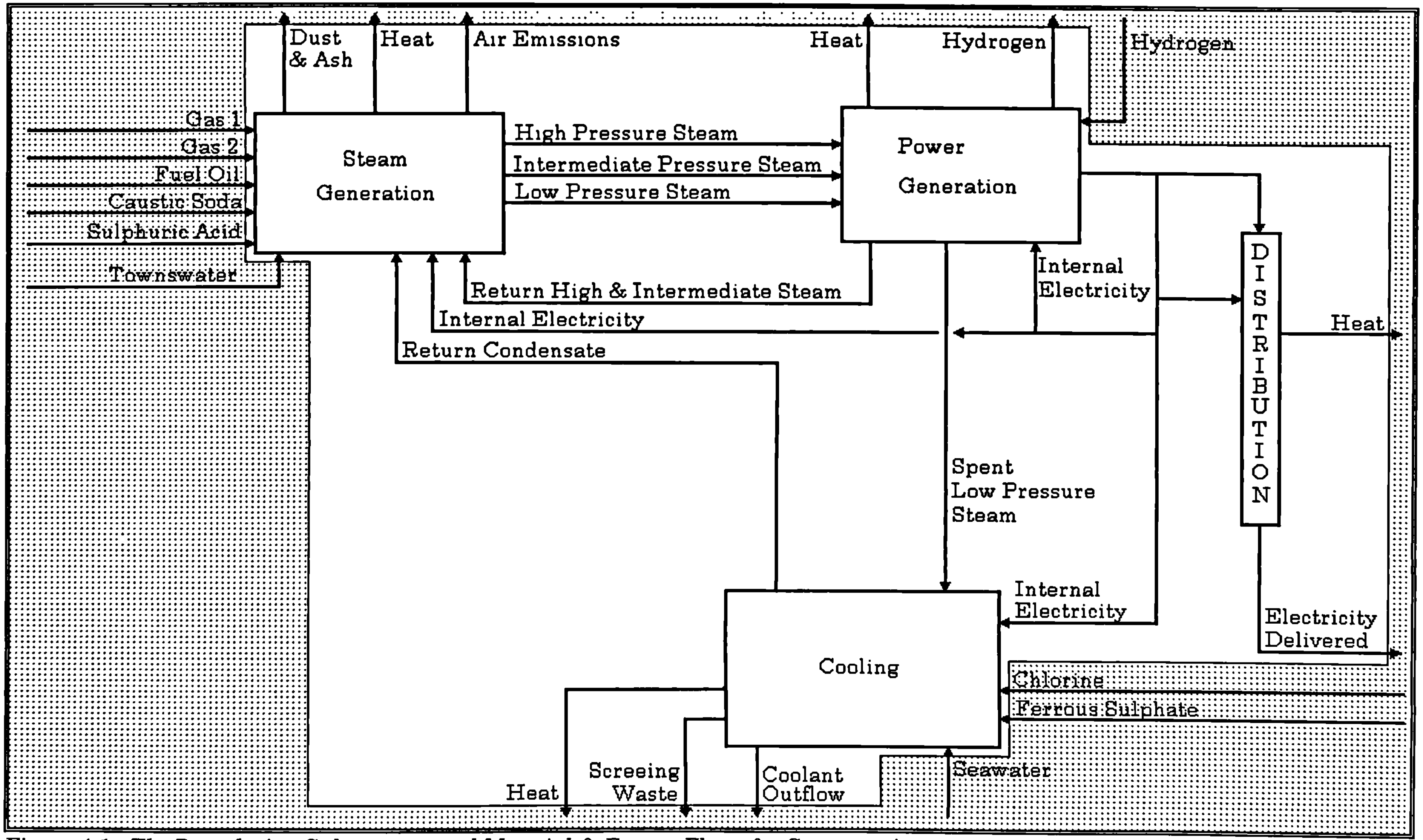


Figure 4.1 - The Boundaries, Sub-systems and Material & Energy Flows for Company A.

4.2.1.1 Emissions to Air.

Direct emissions to air primarily consist of the combustion products from the fuels. Emission data was available for NOx and SO_2, with estimates calculated for CO_2, particulates, nickel and vanadium from a number of different sources (see Table 4.1).

Table 4.1 - Fuel Combustion Emissions to Air from Company A (Kg).

Parameter	CO_2	SO_2	NOx	V	Ni	Parts
Period						
7	373,772,019	420,000	1,279,000	129	39	9,551
8	500,210,649	402,000	1,724,000	114	34	8,472
9	617,963,651	223,000	851,000	44	13	3,278
10	515,454,810	190,000	774,000	35	11	2,609
11	466,832,568	371,000	712,000	109	33	8,109
12	578,312,479	239,000	903,000	50	15	3,745
1	508,569,962	187,000	784,000	30	9	2,254
2	475,592,515	115,000	738,000	8	2	5,66
3	585,873,593	246,000	713,000	50	15	3,730
4	501,448,014	125,000	767,000	7	2	539
5	475,095,993	125,000	723,000	9	3	686
6	298,706,514	135,000	465,000	24	7	1,764

Carbon Dioxide.

Theoretical CO_2 emissions were calculated using sample data on the carbon content of the fuels used.

Equation 4-1 - Stoichiometric Combustion of Fuel Oil CHN.

$$C_{0\,8890}H_{0\,1081}N_{0\,0029} + 0.9190O_2 \rightarrow 0.8890CO_2 + 0.0541H_2O + 0.0029NO_2.$$

Fuel oil CHN data, available from analyses, was used to derive an emission factor for CO_2, using the composition data in Table 4.2 together with Equation 4-1. This equation shows the stoichiometric combustion of fuel oil CHN, assuming a standard ratio of 88.90% carbon, 10.81% hydrogen and 0.29% nitrogen.

Table 4.2 - Composition Data for Fuel Oil CO_2 emissions at Company A.

Fuel Oil Composition					
Parameter	CHN	Sulphur	Ash	Water	
Composition (%)	96.820%	2.740%	0.050%	0.390%	
Stack Ash Composition					
Parameter	Water	Combustibles	Ash	-	
Av. Composition (%)	36.233	51.256	12.511	-	
Relative to Ash	2.896	4.096	1.000	-	
Emission Factors					
Parameter	Ash CHN	Ash Water	Parts	CO_2	SO_2
Factor (Kg / Kg Fuel)	0.002	0.001	0.004	3.488	0.055

A similar approach has been taken for the gases, using the composition data given in Table 4.3 for Gas 1 and Table 4.5 for Gas 2. As no data was available from the Gas 2 supplier, natural gas composition data was adapted by removing the additives present in domestic gas.

Table 4.3 - Average Composition Data for Gas 1 used at Company A.

Constituent	Formula	Average
Nitrogen	N_2	0.950%
Carbon dioxide	CO_2	22.477%
Methane	CH_4	57.270%
Ethane	C_2H_6	9.723%
Propane	C_3H_8	6.553%
i-Butane	C_4H_{10}	2.213%
i-Pentane	C_5H_{12}	0.563%
C6+	C_6H_{14}	0.233%
Hydrogen sulphide	H_2S	0.017%

Table 4.4 - Theoretical Emission Factors for CO_2 from Gas 1.

Constituent	Emission Factor (Kg / Kg Constituent)
Nitrogen	0.00
Carbon dioxide	1.00
Methane	2.74
Ethane	2.93
Propane	2.99
Butane	3.03
Pentane	3.05
C6+	3.06
Hydrogen sulphide	0.00

The gas composition data was combined with usage data to calculate the amount of each constituent burnt. Emission factors for the stoichiometric combustion of each constituent were then used to calculate total CO_2 emissions (see Table 4.4 and Table 4.6).

Table 4.5 - Composition Data used for Gas 2 at Company A.

Constituent	Formula	Percentage
Methane	CH_4	87.450%
Ethane	C_2H_6	6.980%
Propane	C_3H_8	2.190%
Butane	C_4H_{10}	0.410%
Pentane	C_5H_{12}	0.050%
Hexane	C_6H_{14}	0.012%
Heptane	C_7H_{16}	0.005%
Octane	C_8H_{18}	0.002%
Nonane	C_9H_{20}	0.001%
Hydrogen sulphide	H_2S	0.000%
Nitrogen	N_2	0.990%
Carbon dioxide	CO_2	1.910%

Adapted from British Gas (1994).

Table 4.6 - Theoretical Emission Factors for CO_2 from Gas 2.

Constituen	Emission Factor (Kg/Kg Constituent
Methane	2.74
Ethane	2.93
Propane	2.99
Butane	3.03
Pentane	3.05
Hexane	3.06
Heptane	3.07
Octane	3.08
Nonane	3.09
Hydrogen sulphide	0.00
Nitrogen	0.00
Carbon dioxide	1.00

Particulates & Heavy Metals.

Data on the quantity of particulate matter emitted from the process was not available, with very little being available on its constituents. This in stark contrast that for coal (see Smith 1987). However, as particulates are removed from the flue gases and disposed as Special Waste, some heavy metals do have to be sampled. This data has been used to estimate emissions of these metals. The constituent data shown in Table 4.2, together with data from the ash samples (see Table 4.7), was used to calculate emission factors for five metals. Stack ash composition data was used to bring these together into a particulate emission factor (see Table 4.2). Fuel usage data was then used to estimate emissions, using a removal factor of 62.5% for the cyclones.

Table 4.7 - Average Composition & Emission Factors for Fuel Oil Ash (%).

Parameter	Average %	Normalised %	As Fuel %
V	11.034	10.765%	0.005%
Ni	3.329	3.248%	0.002%
Na	2.637	2.573%	0.001%
Ca	8.597	8.388%	0.004%
Mg	9.174	8.950%	0.004%
Unaccounted	67.726	66.076%	0.033%

4.2.1.2 Emissions to Water.

Direct emissions to water occur as 'blow-down' water or demineralisation effluent. As no data on the chemicals contained in the water is available, a theoretical mass balance has been calculated for all substances released to water from the site in section 4.2.3.1. These calculations assumed that all the demineralised water used is eventually released as blow-down water together with the demineralisation chemicals used.

4.2.2 Power Generation.

The power generation system converts the high, intermediate and low pressure steam from steam generation into rotational energy, by passing it through a series of turbines. The steam turbines drive an alternator, which converts the rotational energy into electrical energy. Hydrogen is used in the alternators as a sealant. This electricity is passed to the distribution system via a sub-station, with some of the electricity being used for auxiliary plant. Steam from the high and intermediate pressure turbines is returned to the boilers for further heating, with steam from the low pressure turbines being passed to the cooling system.

4.2.2.1 Process Emissions.

Hydrogen gas is the only direct emission from power generation. However, this gas is not covered by the indices.

4.2.3 Cooling.

The cooling system converts steam from the low pressure turbines into water at around 34 C, for return to steam generation. This occurs in condensers below the turbines, where the steam is passed over tubes filled with sea water, the coolant. The sea water is screened for rough particles and treated to prevent corrosion and microbial activity. Pumps, powered by electricity, push the water through the condensers and return it to sea via an outfall pipe.

4.2.3.1 Process Emissions.

Direct emissions from cooling occur solely to water. No relevant emission data was available for the cooling system. Although sample data for chlorine and pH is taken at regular intervals, these parameters are presently not covered by the indices.

Table 4.8 - Emissions to Water from Company A (Kg).

Parameter	Hg	Cd	Cu	As	Pb	NH^{4+}	Fe
Period							
7	0.011	0.00036	0.00010	0.001	0.000032	304	1,353
8	0.012	0.00039	0.00012	0.001	0.000040	422	1,353
9	0.014	0.00046	0.00010	0.001	0.000033	326	1,691
10	0.013	0.00044	0.00009	0.001	0.000030	378	1,353
11	0.013	0.00042	0.00011	0.001	0.000037	326	1,353
12	0.016	0.00055	0.00026	0.002	0.000085	334	1,691
1	0.011	0.00038	0.00009	0.001	0.000030	237	1,353
2	0.015	0.00051	0.00013	0.001	0.000042	200	1,989
3	0.017	0.00057	0.00015	0.001	0.000050	260	3,282
4	0.016	0.00055	0.00018	0.001	0.000060	319	2,626
5	0.015	0.00049	0.00008	0.001	0.000026	222	2,626
6	0.016	0.00054	0.00017	0.001	0.000058	178	3,282

To estimate mass emissions from the site, a mass balance was calculated for all emissions to water, including water blow-down and demineralisation (see section 3.6.3). The constituents of the sea-water and towns-water were not included in the mass balance, as these form part of the present environment. The resulting emissions relevant to the indices are given in Table 4.8.

4.2.4 Distribution.

Distribution of the generated electricity to customers takes place via a network of transmission lines, sub-stations and transformers. Transmission occurs along 275kV, 132kV and 33/11kV lines, for long and intermediate distance, and local distribution respectively.

Table 4.9 - Distribution Losses from Company A (GJ).

Period	Output GWh	Distribution Losses	Transformer Losses	Transmission Losses	Total Losses
Loss Factor		0.0835	0.025	0.031	
7	497	149,425	44,738	55,475	249,638
8	663	199,340	59,683	74,007	333,029
9	716	215,316	64,466	79,938	359,719
10	677	203,426	60,906	75,523	339,855
11	614	184,442	55,222	68,475	308,139
12	789	237,103	70,989	88,026	396,118
1	691	207,655	62,172	77,094	346,921
2	644	193,511	57,938	71,843	323,291
3	626	188,233	56,357	69,883	314,474
4	677	203,526	60,936	75,561	340,023
5	630	189,277	56,670	70,270	316,217
6	401	120,468	36,068	44,725	201,261

4.2.4.1 Process Emissions.

Direct emissions consist of heat loss from the power lines, due to the electrical resistance of the materials used. These losses occur as both infra-red and Electro-Magnetic Radiation (EMR). There is currently public concern about EMR, but the parameter is not included in either of the indices. As no data was available on the proportion emitted as EMR, it was assumed that all losses occur as heat. Company long-term loss data was used to estimate the heat losses, as shown in Table 4.9.

4.2.5 Site Parameters.

A number of parameters used by TEPI are relevant to all the processes and are best covered as a whole for the site.

4.2.5.1 Internal Transport.

All products within the site are transported by cable or pipe and stored in tanks. There are, therefore, no direct emissions from this function.

4.2.5.2 Land Area.

The area of land owned by the site covers 202,350m^2. It is assumed that all of this land is covered by the site's operations.

4.2.5.3 Heat Losses.

Heat is lost from the site via the cooling water, stack and during conversion. Site thermal efficiency data was used to estimate heat losses, as shown in Table 4.10.

Table 4.10 - Heat Losses from Company A (GJ).

Period	Fuel Heat Value	Thermal Efficiency	Heat Loss
7	4,755,813	38.60%	2,919,921
8	6,419,180	38.06%	3,975,968
9	8,000,965	32.96%	5,363,893
10	6,621,938	37.62%	4,130,810
11	5,932,811	38.13%	3,670,715
12	7,415,204	39.22%	4,507,016
1	6,471,225	39.39%	3,922,497
2	6,079,812	39.19%	3,697,029
3	7,445,810	31.30%	5,115,173
4	6,344,259	39.31%	3,850,643
5	6,006,161	38.67%	3,683,503
6	3,815,347	38.94%	2,329,836

4.2.5.4 Electricity Use.

Company A does not use any externally generated electricity, with all usage supplied by the site itself.

4.3 The Integrated Environmental Index.

The IEI is calculated for those substances released via point-sources. All releases are firstly tested for significance, as discussed in section 2.3.3. The required release rates have been calculated using the site running hours to give a monthly average. The release rates and significance limits for emissions to air are given in Table 4.11. Releases to coastal waters do not presently have a set of significance limits in the BPEO methodology. Significant releases are shown in **bold** or underlined.

Table 4.11 - Air Release Rates & Limits for Company A (g/s).

Parameter Period	Running Hours (Average)	SO_2	NO_x	Ni	Parts.
7	537.01	**217.3**	**661.6**	0.020	4.9
8	672.00	**166.2**	**712.6**	0.014	3.5
9	904.61	**94.9**	**362.2**	0.006	1.4
10	638.91	**82.6**	**336.5**	0.005	1.1
11	642.88	**160.3**	**307.6**	0.014	3.5
12	793.53	**83.7**	**316.1**	0.005	1.3
1	672.00	**77.3**	**324.1**	0.004	0.9
2	669.88	47.8	**306.9**	0.001	0.2
3	817.46	**83.6**	**242.3**	0.005	1.3
4	672.00	51.7	**317.0**	0.001	0.2
5	672.00	51.7	**298.9**	0.001	0.3
6	525.04	**87.6**	**301.6**	0.005	1.1
Air Limit		71.8	82.1	0.042	50.7
Land Limit		N/A	N/A	1.560	N/A

Bold = Significant release for air quality.
Underlined = Significant release for deposition to land.
Limits calculated for stack height of 170.6m from HMIP (1995b).

For those substances released at a significant rate during a given month, a more detailed assessment must be carried out, using the modelling techniques described in section 3.3.

4.3.1 Emissions to Air.

For releases to air the ISCLT model combines meteorological and topographic data with technical data to predict the dispersion of significant releases from Table 4.11. The technical data for the site is given in Table 4.12.

Table 4.12 - Technical Data for Air Emissions from Company A.

Parameter	Value
Stack Height (m)	170.6
Exit Diameter (m)	9.4
Exit Velocity (m/s)	20
Exit Temperature (°C)	135
X Co-ordinate (m)	0
Y Co-ordinate (m)	0

Meteorological data from Leuchars was used (Meteorological Office 1995a), with topographic data derived from a local Ordnance Survey (1987a) map (see Table 4.13).

Table 4.13 - Polar Grid Elevation Heights for Company C (m).

Distance (m) Direction ( )	50	250	500	750	1,000	2,000	3,000	4,000	5,000	10,000
45	25	15	0	0	0	0	0	0	0	0
90	25	15	0	0	0	0	0	0	0	0
135	25	25	20	15	10	0	0	0	0	0
180	25	25	25	30	35	55	0	0	0	0
225	25	25	30	35	50	85	85	50	30	60
270	25	25	35	45	50	60	60	80	65	55
315	25	25	20	30	30	35	40	35	35	50
360	25	15	0	0	0	0	20	15	0	0
Base Height										25

Polar grid co-ordinates centred on (0 , 0).
From Ordnance Survey (1987a).

Using the above data the model was run for each substance in each month to predict the location with the maximum average annual concentration. Table 4.14 shows the results for significant releases from Company A. The table also shows the Environmental Quality Standards (EQSs) or Environmental Action Limits (EALs) for the substances concerned. These are used to calculate the Environmental Quotient (EQ) for air (see Table 4.15), as described in section 2.3.3.

Table 4.14 - Predicted Concentrations in Air for Company A (ug/m³).

Parameter	Period EQS / EAL (ug/m³)	7	8	9	10	11	12	1	2	3	4	5	6
SO_2	80	3.368	2.576	1.472	1.281	2.485	1.297	1.198	0.741	1.296	0.801	0.801	1.357
NO_x	50	10.257	11.048	5.616	5.217	4.770	4.901	5.024	4.758	3.756	4.915	4.633	4.675

Table 4.15 - Environmental Quotients (EQ s) and EQ $_{Air}$ for Company A.

Period Parameter	7	8	9	10	11	12	1	2	3	4	5	6
SO_2	0.042	0.032	0.018	0.016	0.031	0.016	0.015	0.009	0.016	0.010	0.010	0.017
NO_x	0.205	0.221	0.112	0.104	0.095	0.098	0.100	0.095	0.075	0.098	0.093	0.094
$EQ_{(Air)}$	0.247	0.253	0.131	0.120	0.126	0.114	0.115	0.104	0.091	0.108	0.103	0.110

In the BPEO methodology (HMIP 1995b) the EQS for NO_X is given, not as an annual average, but as a 98th percentile. As the meteorological data required to calculate 98th percentile values was not available, the annual average limit value for NO_X was used as a substitute.

4.3.2 Emissions to Water.

Emissions to coastal waters do not presently have a set of significance limits in the BPEO methodology. It has, therefore, been assumed that the EQ for water is zero.

4.3.3 Emissions to Land.

Company A has no significant direct or indirect releases to land (see Table 4.11) The EQ for land is, therefore, zero.

Table 4.16 - $EQ_{Air)}$, EQ_{Water} $EQ_{Land)}$ *and the IEI for Company A.*

Period	$EQ_{Air)}$	$EQ_{Water)}$	$EQ_{(Land)}$	IEI
7	0.247	0.000	0.000	0.247
8	0.253	0.000	0.000	0.253
9	0.131	0.000	0.000	0.131
10	0.120	0.000	0.000	0.120
11	0.126	0.000	0.000	0.126
12	0.114	0.000	0.000	0.114
1	0.115	0.000	0.000	0.115
2	0.104	0.000	0.000	0.104
3	0.091	0.000	0.000	0.091
4	0.108	0.000	0.000	0.108
5	0.103	0.000	0.000	0.103
6	0.110	0.000	0.000	0.110

4.3.4 The Integrated Environmental Index.

The EQs for air, water and land, and the resulting IEI for Company A are shown in Table 4.16.

4.4 The Total Environmental Potency Index.

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 4.1, and Table 4.8 - Table 4.10. Each of the substances covered by the TEPI is allocated a series of potency factors which describe its contribution to different environmental potency categories, as discussed in section 3.4. The category totals and TEPI from these emissions are given in Table 4.17. The site does not import any electricity, utilising its own electricity for internal use.

Table 4.17 - Category Totals & TEPI for Company A (x1000).

Period Category	7	8	9	10	11	12	1	2	3	4	5	6
GWP	373,772	500,211	617,964	515,455	466,833	578,312	508,570	475,593	585,874	501,448	475,096	298,707
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	1411	1409	604	508	1,103	670	472	270	620	277	281	329
AETP	6	6	3	3	5	4	3	2	4	2	2	3
TETP	65,348	57,983	22,506	17,934	55,512	25,722	15,492	3,994	25,626	3,821	4,811	12,182
POCP	0	0	0	0	0	0	0	0	0	0	0	0
AP	1315	1609	819	732	869	871	736	632	745	662	631	461
NP	166	224	111	101	93	117	102	96	93	100	94	60
WH	3,170	4,309	5,724	4,471	3,979	4,903	4,269	4,020	5,430	4,191	4,000	2,531
LA	182	182	182	182	182	182	182	182	182	182	182	182
TEPI	445,370	565,932	647,912	539,385	528,576	610,782	529,826	484,789	618,573	510,682	485,097	314,455

CHAPTER FIVE

Company B

Heat and Power

5.1 The Company.

Company B is a Combined Heat and Power (CHP) plant operated by a refinery owned by a large UK oil company. The site supplies electricity and steam to the refinery and two other companies in the vicinity, with additional electricity imported from the grid. The plant operates under an IPC authorisation, and has emission limits set under the LCP Directive. The refinery site supports 1,000 employees, from a total of 56,000 people within the parent company. Environmental management at the site is carried out from an EHS department, by the environmental leader. The site is not accredited to an environmental management standard, but both the refinery and the parent company produce an annual environmental report, which is publicly available. Company B is participating as a black box site.

5.2 The Heat and Power Generation Process & Emissions.

Company B provides the utilities of steam and electrical power to the refinery site and two other local companies. The flows to and from the site are shown in Figure 5.1.

Steam is generated in seven boilers, which are fired on gas, light fuel oil, heavy fuel oil and tar oil. These fuels are supplied by the refinery in varying quantities dependent upon the materials being refined. Heavy fuel oil is used as the base load, with the remainder supplementing the fuel mix to satisfy the steam load of the sites. Electricity generation is limited by this load, with additional electricity imported from the grid. The boilers are supplied with water from a demineralisation plant, which uses a variety of chemical products to remove oxygen and salts from the towns-water supplied (see Figure 5.1).

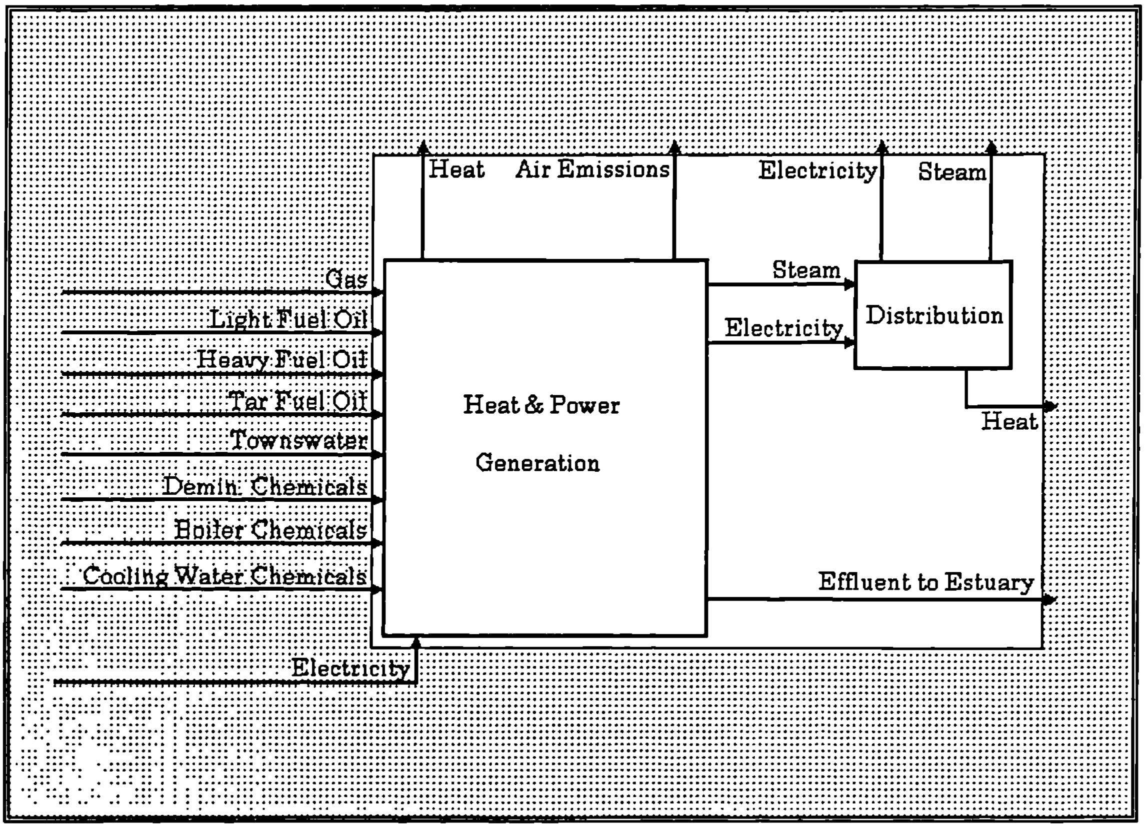


Figure 5.1 - The Boundaries and Material & Energy Flows for Company B.

Additional products are used as corrosion inhibitors for the boilers and to control microbial activity in the cooling towers.

5.2.1 Emissions to Air.

Direct emissions to air primarily consist of the combustion products from the fuels. Emission data was available for NO_x and SO_2, with estimates calculated for a number of additional parameters, as shown in Table 5.1. Emission estimates for CO_2, particulates and some metals have been derived from different sources for the fuel oils and gas burnt.

Fuel oil emission factors were calculated for CO_2, particulates, nickel and vanadium, using fuel usage data to estimate monthly emissions (see Table 5.2). The CO_2 factor was calculated using the stoichiometric combustion of the fuel

Table 5.1 - Fuel Combustion Emission to Air from Company B (Kg).

Parameter	CO_2	SO_2	NO_x	V	Ni	Particulates
Period						
9	103,596,859	591,000	165,000	496	150	36,821
10	116,469,470	681,000	172,000	489	147	36,270
11	111,457,651	640,000	170,000	487	147	36,149
12	126,118,534	660,000	192,000	511	154	37,925
1	124,211,041	677,000	179,000	416	125	30,910
2	126,020,324	985,000	208,000	580	175	43,096
3	110,570,852	668,000	175,000	474	143	35,206
4	110,762,740	563,000	146,000	399	120	29,640
5	107,358,142	675,000	159,000	418	126	31,041
6	111,128,213	658,000	181,000	548	165	40,705
7	100,824,022	584,000	124,000	302	91	22,424
8	110,174,146	837,000	140,000	333	100	24,713

according to equation 4.1, which was then adjusted for the carbon content in each fuel type (see Table 5.2). Little data was available on the ash composition of the fuel oils, either from the site, the refinery or the crude oil suppliers on the remaining parameters. Data on the composition of heavy fuel oil ash from Company A was, therefore, adjusted to reflect the ash content of the different fuel oils used at the site (see Table 4.7). Emission factors were then calculated, as shown in Table 5.2.

Table 5.2 - Composition & Emission Factors for Fuel Oils at Company B.

Fuel Composition			
Substance	Light Fuel Oil	Heavy Fuel Oil	Tar Fuel Oil
CHN	97.850%	97.170%	96.520%
S	1.640%	1.810%	1.950%
H_2O	0.010%	0.020%	0.030%
Ash	0.500%	1.000%	1.500%
Emission Factors (Kg/Kg Fuel)			
CO_2	3.53091	3.50488	3.47994
V	0.00001	0.00002	0.00003
Ni	0.00000	0.00001	0.00001
Ash CHN	0.00041	0.00082	0.00123
Ash H_2O	0.00029	0.00058	0.00087
Particulates	0.00080	0.00160	0.00510

CO_2 emissions from gas combustion were also derived using a substitute. Gas emission factors from Company A, which uses an oil-field derived gas (see Table 4.3), were used to estimate the amount of CO_2 emitted from usage data. The emission factors used are shown in Table 4.4. The monthly total emissions from these calculations and the company data for the site are shown in Table 5.1.

5.2.2 Emissions to Water.

Direct releases to water consist of blowdown water and cooling water treatment chemicals. These chemicals are all passed onto a biological treatment plant, before being discharged to estuarine surface waters.

As the biological treatment plant also receives effluent from other sites, those parameters measured could not be related back to the CHP plant. To estimate these emissions a mass balance has been constructed, as described in section 3.6.3. A Water Treatment Removal Factor (WTRF) of 70% was applied to the monthly constituent totals obtained, leaving an estimate for the amount of each substance released into the environment. The relevant substances emitted are summarised in Table 5.3.

5.2.3 Distribution.

The products from Company B are distributed using pipes and cables for steam and electricity respectively. Other than losses along the line, there are no direct distribution emissions associated with this function. These losses are assumed to be included in the efficiency figures for the site.

5.2.4 Site Parameters.

A number of parameters used by TEPI are relevant to all of the process and are best covered as a whole for the site.

Table 5.3 - Emissions to Water from Company B (Kg).

Parameter	Fe	Cu	As	Pb	Hg	Ni	Zn	NH^{4+}	Cd
Period									
9	0.33	0.00000	0.000000	0.000000	0.014	0.00000	17.88	0.80	0.00047
10	0.40	0.00000	0.000000	0.000000	0.015	0.00000	17.88	0.74	0.00050
11	0.37	0.00030	0.000015	0.000015	0.014	0.00045	21.46	0.67	0.00046
12	0.36	0.00000	0.000000	0.000000	0.012	0.00000	22.89	0.70	0.00041
1	0.38	0.00000	0.000000	0.000000	0.014	0.00000	19.31	0.80	0.00047
2	0.38	0.00030	0.000015	0.000015	0.014	0.00045	20.03	0.74	0.00048
3	0.37	0.00000	0.000000	0.000000	0.015	0.00000	22.17	0.84	0.00050
4	0.41	0.00015	0.000008	0.000008	0.016	0.00023	19.31	0.90	0.00053
5	0.36	0.00000	0.000000	0.000000	0.014	0.00000	25.03	0.85	0.00047
6	0.35	0.00015	0.000008	0.000008	0.013	0.00023	17.88	0.74	0.00043
7	0.38	0.00000	0.000000	0.000000	0.015	0.00000	21.46	0.79	0.00051
8	0.39	0.00000	0.000000	0.000000	0.014	0.00000	22.17	0.87	0.00047

5.2.4.1 Internal Transport.

All materials within the site are transported by pipe and stored in tanks. There are, therefore, no direct emissions from this function.

5.2.4.2 Heat Losses.

Table 5.4 - Heat Losses from Company B.

Parameter Period	Energy In (GJ)	Efficiency (%)	Heat Loss (GJ)
9	1,587,325	85.57	229,051
10	1,882,064	85.80	267,253
11	1,796,570	85.62	258,347
12	1,995,753	85.61	287,189
1	2,061,150	85.41	300,722
2	1,845,044	85.56	266,424
3	1,752,502	85.21	259,195
4	1,905,985	85.40	278,274
5	1,741,428	85.38	254,597
6	1,688,403	85.32	247,858
7	1,798,987	85.48	261,213
8	1,923,652	85.33	282,200

Heat losses from the site occur via the boiler stack and cooling towers. These losses have been estimated using boiler efficiency data from the site (see Table 5.4). Energy inputs were calculated from fuel usage and calorific value data. It is assumed that the steam used in the turbines and on site performs useful work and is not lost.

5.2.4.3 Land Area.

The area of land allocated to the site covers 65,000m^2. It is assumed that all of this land is covered by the site's operations.

5.2.4.4 Electricity Use.

Electricity is a minor secondary source of energy for the site. Although the use of electricity has no direct environmental burden. it will be used to estimate the contribution of an indirect process on the company. The usage figures used to calculate this contribution, from the emissions of a variety of electricity generators, are given in Table 5.5.

Table 5.5 - Electricity Use at Company B (KWh).

Period	9	10	11	12	1	2
Usage	9,030 ,000	15,699 ,000	13,130 ,000	7,592 ,000	9,781 ,000	5 ,000
Period	3	4	5	6	7	8
Usage	17,563 ,000	12,786 ,000	14,636 ,000	15,399 ,000	17,055 ,000	11,245 ,000

5.3 The Integrated Environmental Index.

The IEI is calculated for those substances released via point-sources. All releases are firstly tested for significance, as discussed in section 2.3.3. The required release rates have been calculated using the site running hours to give a monthly average. The release rates and significance limits for emissions to air are given in

Table 5.6 - Air Release Rates & Limits for Company B (g/s).

Parameter	Running Hours	SO_2	NO_x	Ni	Parts.
Period					
9	720	**228.0**	**63.7**	**0.058**	14.21
10	744	**254.3**	**64.2**	**0.055**	13.54
11	720	**246.9**	**65.6**	**0.057**	13.95
12	744	**246.4**	**71.7**	**0.058**	14.16
1	744	**252.8**	**66.8**	**0.047**	11.54
2	672	**407.2**	**86.0**	**0.072**	17.81
3	744	**249.4**	**65.3**	**0.053**	13.14
4	720	**217.2**	**56.3**	**0.046**	11.44
5	744	**252.0**	**59.4**	**0.047**	11.59
6	720	**253.9**	**69.8**	**0.063**	15.70
7	744	**218.0**	**46.3**	**0.034**	8.37
8	744	**312.5**	**52.3**	**0.037**	9.23
Air Limit		10.8	12.4	0.006	21.62
Land Limit		N/A	N/A	0.240	N/A

Bold = Significant release for air quality.
Underlined = Significant release for deposition to land.
Limits calculated for stack height of 84m from HMIP (1995b).

Table 5.7 - Water Release Rates & Limits for Company B (ug/s).

Parameter	Fe	Cu	As	Pb	Hg	Ni	Zn	NH^{4+}	Cd
Period									
9	12	0.000	0.000	0.000	0.538	0	690	31.019	0.018
10	15	0.000	0.000	0.000	0.554	0	668	27.516	0.018
11	14	0.012	0.001	0.000	0.535	0	828	25.849	0.018
12	14	0.000	0.000	0.001	0.460	0	855	26.266	0.015
1	14	0.000	0.000	0.000	0.521	0	721	30.018	0.017
2	16	0.012	0.001	0.000	0.592	0	828	30.465	0.020
3	14	0.000	0.000	0.001	0.565	0	828	31.269	0.019
4	16	0.006	0.000	0.000	0.615	0	745	34.896	0.020
5	13	0.000	0.000	0.000	0.531	0	935	31.894	0.018
6	13	0.006	0.000	0.000	0.497	0	690	28.434	0.017
7	14	0.000	0.000	0.000	0.571	0	801	29.393	0.019
8	14	0.000	0.000	0.000	0.528	0	828	32.519	0.018
Limit	36,330	181.650	908.250	908.250	10.900	1,089	1,4530	514.656	90.825

Bold = Significant release for water quality.
Limits calculated for nominal flow rate of 18.165 m^3/s from HMIP (1995b).
Nominal flow rate from SEPA (1996d-h).

Table 5.6 and in Table 5.7 for water. Significant releases are shown in **bold** or underlined.

For those substances released at a significant rate during a given month, a more detailed assessment must be carried out, using the modelling techniques described in section 3.3.

5.3.1 Emissions to Air.

For releases to air the ISCLT model combines meteorological and topographic data with technical data to predict the dispersion of significant releases from Table 5.6. The technical data for the site is given in Table 5.8.

Table 5.8 - Technical Data for Emissions from Company B.

Parameter	Stack 1	Stack 2	Stack 3
Stack Height (m)	91	84	91
Exit Diameter (m)	3.3	2.1	2.4
Exit Velocity (m/s)	14.7	18.1	22.8
Exit Temperature (°C)	180	180	180
X Co-ordinate (m)	0	10	20
Y Co-ordinate (m)	0	0	0

Meteorological data from Turnhouse (Meteorological Office 1995c) was used, with topographic data derived from local Ordnance Survey (1976 & 1987b) maps (see Table 5.9).

Table 5.9 - Polar Grid Elevation Heights for Company B (m).

Distance (m)	50	100	250	500	750	1,000	2,000	3,000	4,000	5,000
Direction (°)										
45	10	10	10	10	10	10	0	0	0	0
90	10	10	10	10	10	0	0	10	10	45
135	10	10	10	10	10	10	60	60	30	45
180	10	10	10	10	10	10	60	60	90	105
225	10	10	10	10	10	10	10	15	60	75
270	10	10	10	10	10	10	10	10	10	10
315	10	10	10	10	10	10	10	10	10	10
360	10	10	10	10	10	10	10	0	0	15
Base Height										10

Polar grid co-ordinates centred on (0 , 0).
From Ordnance Survey (1976 & 1987b).

Table 5.10 - Predicted Concentrations in Air for Company B (ug/m).

Parameter	EQS / EAL (ug/m^3)	9	10	11	12	1	2	3	4	5	6	7	8
SO_2	80	8.3960	9.3625	9.0922	9.0738	9.3075	14.9929	9.1838	7.9982	9.2800	9.3478	8.0289	11.5073
NOx	50	2.3441	2.3647	2.4151	2.6397	2.4609	3.1661	2.4059	2.0742	2.1860	2.5714	1.7048	1.9247
Ni	0.2	0.0021	0.0020	0.0021	0.0021	0.0017	0.0027	0.0020	0.0017	0.0013	0.0023	0.0013	0.0014

Table 5.11 - Environmental Quotients (EQ s) and EQ $_{Air}$ for Company B.

Period Parameter	9	10	11	12	1	2	3	4	5	6	7	8
SO_2	0.1049	0.1170	0.1137	0.1134	0.1163	0.1874	0.1148	0.1000	0.1160	0.1168	0.1004	0.1438
NOx	0.0469	0.0473	0.0483	0.0528	0.0492	0.0633	0.0481	0.0415	0.0437	0.0514	0.0341	0.0385
Ni	0.0105	0.0099	0.0105	0.0105	0.0086	0.0133	0.0099	0.0086	0.0066	0.0116	0.0062	0.0072
$EQ_{(Air)}$	0.1623	0.1743	0.1724	0.1767	0.1742	0.2640	0.1729	0.1500	0.1663	0.1799	0.1407	0.1895

Using the above data the model was run for each substance for each month to predict the location with the maximum average annual concentration. Table 5.10 shows the results for significant releases from Company B. The table also shows the EQSs or EALs for the substances concerned. These are used to calculate the EQ for air (see Table 5.11), as described in section 2.3.3. In the BPEO methodology (HMIP 1995b) the EQS for NOx is given, not as an annual average, but as a 98th percentile. As the meteorological data required to calculate 98th percentile values was not available, the annual average limit value for NOx was used as a substitute.

5.3.2 Emissions to Water.

Company B has no significant releases to water (see Table 5.7). The EQ for water is, therefore, zero.

5.3.3 Emissions to Land.

Company B has no significant direct or indirect releases to land (see Table 5.6). The EQ for land is, therefore, zero.

Table 5.12 - $EQ_{Air)}$, $EQ_{Water)}$, $EQ_{Land)}$ and the IEI for Company B.

Period	$EQ_{(Air)}$	$EQ_{(Water)}$	$EQ_{(Land)}$	IEI
9	0.1623	0.0000	0.0000	0.1623
10	0.1743	0.0000	0.0000	0.1743
11	0.1724	0.0000	0.0000	0.1724
12	0.1767	0.0000	0.0000	0.1767
1	0.1742	0.0000	0.0000	0.1742
2	0.2640	0.0000	0.0000	0.2640
3	0.1729	0.0000	0.0000	0.1729
4	0.1500	0.0000	0.0000	0.1500
5	0.1663	0.0000	0.0000	0.1663
6	0.1799	0.0000	0.0000	0.1799
7	0.1407	0.0000	0.0000	0.1407
8	0.1895	0.0000	0.0000	0.1895

5.3.4 The Integrated Environmental Index.

The EQs for air, water and land, and the resulting IEI for Company B are shown in Table 5.12.

5.4 The Total Environmental Potency Index.

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 5.1 and Table 5.3. Each of the substances covered by the TEPI is allocated a series of potency factors which describes its contribution to different environmental potency categories, as discussed in section 3.4. The category totals and TEPI from these emissions are given in are given in Table 5.13. In order to assess the effect of electricity use on the site's total potency in section 11.3.3, the usage data in Table 5.5 has been used to calculate the TEPI for electricity, based on the average UK generation mix (see Table 5.14). This data has not been included in the site totals being used for the comparative study.

Table 5.13 - Category Totals and TEPI for Company B (x 1,000).

Period	9	10	11	12	1	2	3	4	5	6	7	8
Category												
GWP	103,596	116,469	111,458	126,119	124,211	126,020	110,571	110,763	107,358	111,128	100,824	110,174
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	4,034	3,992	3,972	4,169	3,426	4,772	3,878	3,265	3,434	4,460	2,499	2,786
AETP	132	139	131	119	129	138	141	145	131	125	136	128
TETP	251,593	247,831	247,006	259,141	211,207	294,471	240,562	202,534	212,103	278,130	153,223	168,865
POCP	0	0	0	0	0	0	0	0	0	0	0	0
AP	707	801	759	794	802	1131	791	665	786	785	671	935
NP	21	22	22	25	23	27	23	19	21	24	16	18
WH	229	267	258	287	301	266	259	278	255	248	261	282
LA	65	65	65	65	65	65	65	65	65	65	65	65
TEPI	360,377	369,587	363,671	390,719	340,164	426,890	356,289	317,734	324,153	394,964	257,695	283,252

Table 5.14 - Category Totals and TEPI for Electricity used at Company B (UK Average).

Period Category	7	8	9	10	11	12	1	2	3	4	5	6
GWP	5,879,015	10,220,892	8,548,596	4,942,800	6,367,956	3,515.690	11,434,456	8,324,373	9,528,822	10,025,576	11,103,721	7,321,099
ODP	0	0	0	0	0	0.000	0	0	0	0	0	0
HTP	8,152	14,172	11,854	6,854	8,830	4.875	15,855	11,543	13,213	13,902	15,397	10,152
AETP	0	0	0	0	0	0.000	0	0	0	0	0	0
TETP	0	0	0	0	0	0.000	0	0	0	0	0	0
POCP	1,868	3,247	2,716	1,570	2,023	1.117	3,633	2,645	3,028	3,185	3,528	2,326
AP	35,053	60,941	50,970	29,471	37,968	20.962	68,177	49,633	56,815	59,777	66,205	43,651
NP	2,234	3,884	3,249	1,878	2,420	1.336	4,345	3,163	3,621	3,810	4,220	2,782
WH	65	113	95	55	71	0.039	127	92	106	111	123	81
LA	3	6	5	3	4	0.002	7	5	5	6	6	4
TEPI	5,926,391	10,303,256	8,617,484	4,982,631	6,419,272	3,544.021	11,526,600	8,391,454	9,605,609	10,106,366	11,193,199	7,380,095

CHAPTER SIX

Company C

Fine Papers

6.1 The Company.

Company C is a fine papers manufacturer, participating as a grey box site. The site produces a variety of writing and security papers, as part of a larger paper products group operating in the UK and North America. The boiler plant at the site is subject to IPC, but an exception has been requested for the papermaking process. The site is accredited to EMAS and ISO14001, and the group produces an environmental report, containing site-specific information, which is publicly available. The site employs 350 people, with a total of 4,100 employees within the group. Environmental matters at the site are the responsibility of the technical manager who reports to the company board.

6.2 The Paper Making Processes & Emissions.

The paper making process has been divided into six sub-systems to help understand how they work, gather data and estimate emissions. These are: stock preparation, paper manufacture, paper finishing, distribution, boiler plant and effluent treatment (see Figure 6.1). The processes and emissions associated with these sub-systems are discussed below.

6.2.1 Stock Preparation.

The stock preparation sub-system converts the input materials into a form suitable for paper manufacture. This primarily entails mixing the fibre and other materials with water to obtain a final composition of 1% fibre. The fibre materials are firstly mixed with water, and possibly bleach, in a pulper to obtain a mixture of 6% fibre. The pulped fibre is then passed through refiners to a mixing chest, where it is combined with more water as well as loadings, sizing, OBA's, dyes, speciality chemicals and return broke to a consistency of 3%. This mixture is then

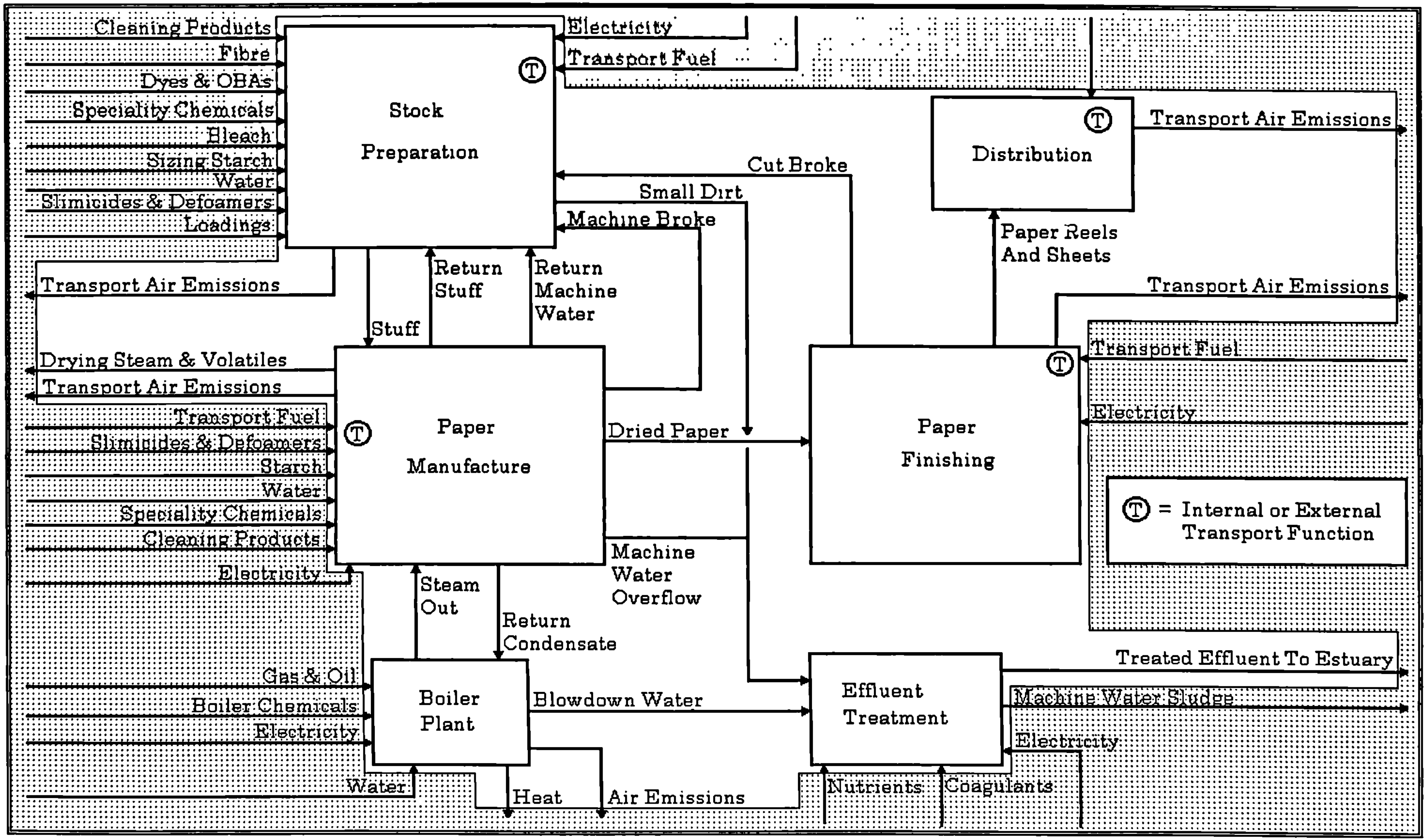


Figure 6.1 - The Boundaries, Sub-systems and Material & Energy Flows for Company C.

referred to as stuff. Defoamers and slimicides are added to prevent frothing and biological growth in the process. Cleaning products are used only when the process is shut down, and thus do not end up in the paper itself. All raw materials are transported to the process using fork-lift trucks, but are pumped once they are in a liquid form. The stuff is finally passed through a set of cyclone filters, which remove any fine dirt, before being mixed with the return machine water to a final consistency of 1% fibre and passed onto paper manufacture.

6.2.1.1 Process Emissions.

Direct emissions from stock preparation consist of releases to air from the fork-lift trucks, which are covered in section 6.2.6. Indirect emissions occur via the paper manufacture and effluent treatment sub-systems, before being released in the effluent. As the number of effluent parameters measured are limited, the remainder have been estimated using a mass balance based on the company's usage figures in section 6.2.5. For those materials used in paper manufacture, removal factors have been calculated in section 6.2.2. Any other materials will pass straight onto the effluent treatment plant.

6.2.2 Paper Manufacture.

The paper manufacture sub-system contains the processes associated with the making of the paper itself. This process has changed little since it was started in 1803 (Watson 1987). The stuff from stock preparation is passed into a head-box which distributes the stuff equally across a synthetic mesh called the "wire" (see Figure 6.2). The wire passes at constant speed from under the head-box to obtain a set grammage of paper. Slimicides and speciality chemicals may be added at this point to prevent biological growth and achieve the paper specifications

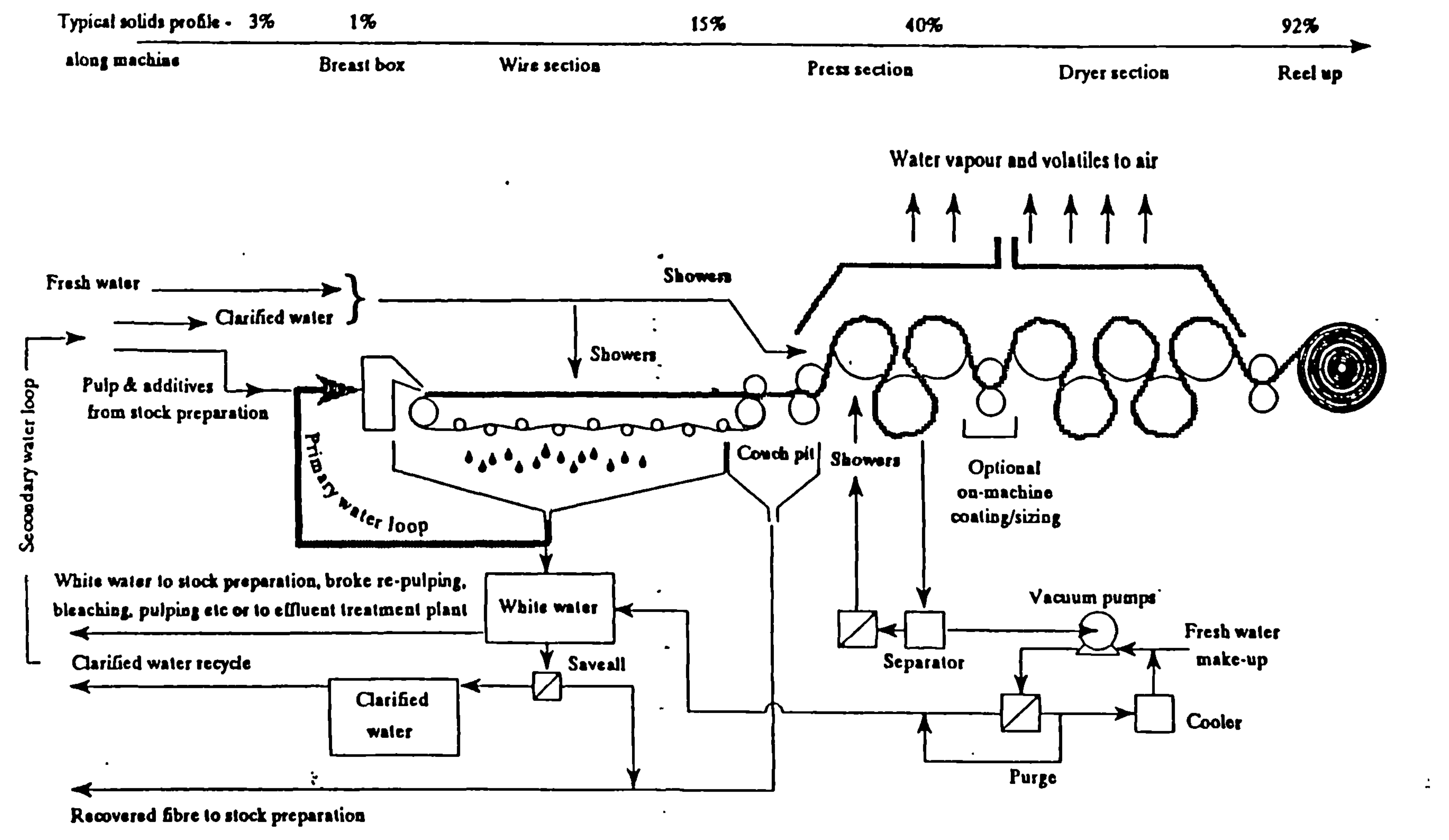


Figure 6.2 - The Paper Making Process.

required. Most of the water passes through the paper and wire into the machine pit below. This water is returned to the head-box and mixed with the incoming stuff. Excess water is stored for use in pulping or removed to effluent treatment as machine water overflow. The edges of the paper are trimmed using high pressure jets, with the excess stuff being fed back to the mixing chest for re-use. Additional water is removed from the paper through a series of vacuum boxes over which the wire passes, with a final vacuum box contained in the couch roll at the end of the wire (see Figure 6.2).

From the couch roll the paper passes onto a set of roll presses, where the paper is pressed between two sets of felt sheets which absorb further water from the paper. This water is extracted from the felt and passed to effluent treatment as machine water overflow. The paper is then dried in two sections by being passed over a set of steam filled drums, passing through a starch size press in the middle. Moisture from the paper is vented to air, with steam from the drying rolls going back to the boiler plant as return condensate. Finally, the paper is passed through a set of calendars, and scanned for grammage, moisture and ash content before being rolled up onto a large reel and passed onto paper finishing.

The company runs three paper machines all supplied by the stock preparation subsystem. The paper machines are run by a series of computers which control pumps, motors and valves, all running on electricity. Cleaning products are used to service the machines and pipes during stoppages and are not incorporated into the paper making process, passing directly to effluent treatment as machine water overflow. Paper reels are transported using fork-lift trucks.

6.2.2.1 Process Emissions.

Direct emissions from this sub-system consist of releases to air from fork-lift trucks, with additional releases of water vapour and volatiles. No data is available on the release of volatile organic compounds from the dryers, so it is assumed that all constituents of the stuff either remain in the paper or are removed to effluent treatment. Water vapour releases have been estimated using the average amount of water in the paper on entry and exit to the drying section. It is also assumed that all the steam supplied to the drying drums is returned to the boiler plant as condensate.

Equation 6-1 - Calculation of Paper Making Removal Factor for Company C.

$$\begin{aligned} \text{PMRF} &= \frac{\text{Dry weight of Paper Manufactured}}{\text{Dry weight of Product In}} \\ &= \frac{39{,}159{,}950 \text{ Tonnes}}{41{,}404{,}049 \text{ Tonnes}} \\ &= 94.58\% \end{aligned}$$

Indirect emissions via the effluent treatment plant have been estimated using a mass balance for the site in section 6.2.5. None of the materials used in stock preparation are removed, but this is not the case here. To estimate how much of each product and its constituents has been incorporated into the paper, material usage data has been used to estimate a Paper Making Removal Factor (PMRF), according to Equation 6-1. This factor was then used to estimate the amount of each chemical used in stock preparation and paper manufacture which remains for effluent treatment. Those products not used in the paper making process, such as cleaning materials, will have a PMRF of 0%. The final emissions from the effluent treatment plant are given in section 6.2.5.

6.2.3 Paper Finishing.

The paper finishing sub-system prepares the paper for dispatch to customers and merchants. Customer specifications can vary from reels of paper to pallets of paper sheets. For all paper specifications the reel from paper manufacture is firstly re-reeled to remove paper that is known to be outside the specifications and trim the edges. The reel may then be split down into smaller or narrower reels, or cut into paper sheets using a range of cutters, depending on customer requirements. Any reject paper is returned to stock preparation as return broke. The product is then packaged and stored ready for dispatch. The cutters all run on electricity and the reels and finished product are all transported using fork-lift trucks.

6.2.3.1 Process Emissions.

Direct emissions from paper finishing consist of releases to air from the fork-lift trucks used (see section 6.2.6). There are no other known emissions.

6.2.4 Boiler Plant.

The boiler plant provides steam for the paper manufacture sub-system to dry the paper. This steam is generated from filtered river water using natural gas or heavy fuel oil in a boiler. The exhaust gases from the boiler are released to air through a single stack. Some of the condensate returned from the drying process is continuously released to the effluent treatment plant as blow-down water. The boilers are operated using electrically powered control equipment and pumps, with no internal transport operations.

6.2.4.1 Process Emissions.

Direct releases from the boiler plant consist of the combustion products from the fuels burned. Indirect emissions of blow-down water occur via the effluent treatment plant. As there is no water usage data available specifically for the boiler plant, it is assumed that all the steam is returned and eventually released as blow-down water. This assumption will be used in the mass balance calculations in section 6.2.5. Air emissions are not monitored or estimated on an annual or monthly basis at the site, so they have been estimated using theoretical or practical emission factors and fuel usage. Emissions of CO_2, SO_2 and NOx have been calculated for natural gas, with additional data on particulates and heavy metals for heavy fuel oil.

Natural Gas.

Mass emissions from natural gas combustion were calculated using the average composition of a typical natural gas (British Gas 1994), as shown in Table 6.1.

Equation 6-2 - Calculation of Mass Usage Data for Company C.

$$Mass\ Usage = \frac{Volumetric\ \ Usage}{22.4} * Molecular\ Weight,$$

Volumetric usage data was converted into mass usage data per constituent, using Table 6.1 and the formula given in Equation 6-2, and multiplied by the stoichiometric emission factors calculated for each constituent in Table 6.2.

Emissions of NOx are not generated directly from the natural gas, as none of its constituents contain chemically bound nitrogen. The NOx that is produced is formed by the reaction of nitrogen and oxygen in the air and gas due to the high temperatures of the burners. This kind of NOx cannot be derived from simple

Table 6.1 - Average Composition of Typical Natural Gas.

Constituent	Percentage	Molecular Weight (g)
Methane	87.44938%	16.042
Ethane	6.97995%	30.068
Propane	2.18998%	44.094
i-Butane	0.41000%	58.120
i-Pentane	0.05000%	72.146
Hexane	0.01200%	86.172
Heptane	0.00500%	100.198
Octane	0.00200%	114.224
Nonane	0.00100%	128.250
Hydrogen sulphide	0.00010%	34.076
Nitrogen	0.98999%	28.020
Carbon dioxide	1.90999%	44.010
Diethyl sulphide	0.00042%	90.183
Tert. butyl mercaptan	0.00006%	200.298
Ethyl mercaptan	0.00013%	62.129

Constituent data from British Gas 1994).

stoichiometric equations. A practical emission factor, from tests carried out on industrial boilers in Scotland by Walker et al (1985), was therefore used to estimate emissions of NO_X.

Table 6.2 - Theoretical Emission Factors for the Constituents of Natural Gas.

Constituents	Emission Factor (Kg/Kg Constituent)		
	CO_2	SO_2	NOx
Methane	2.74	-	-
Ethane	2.93	-	-
Propane	2.99	-	-
i-Butane	3.03	-	-
i-Pentane	3.05	-	-
Hexane	3.06	-	-
Heptane	3.07	-	-
Octane	3.08	-	-
Nonane	3.09	-	-
Hydrogen sulphide	-	1.88	-
Nitrogen	-	-	#-
Carbon dioxide	1.00	-	-
Diethyl sulphide	1.95	1	-
Tert. Butyl mercaptan	2.86	0.32	-
Ethyl mercaptan	1.42	1.03	-
Natural Gas#	-	-	.00192

NOx emission factor from Walker et al. (1985).

Heavy Fuel Oil.

Mass emissions from heavy fuel oil were calculated using a similar constituent based approach. Emissions of CO_2 and SO_2 were estimated from fuel usage using emission factors for the stoichiometric combustion of the carbon and sulphur in the fuel (see Table 4.2). Data on the composition of heavy fuel oil ash was used to calculate emission factors for a number of metals and particulates, as shown in Table 4.7. Finally, emissions of NOx were again calculated using an emission factor from Walker et al. (1985). The estimated releases to air form both fuels are shown in Table 6.3.

Table 6.3 - Fuel Combustion Emissions to Air from Company C (Kg).

Parameter Period	CO_2	SO_2	NOx	V	Ni	Particulates
7	3,338,199	52,348	6,368	51	16	3,818
8	1,112,280	17,476	2,124	17	5	1,274
9	2,941,496	45,928	5,597	45	14	3,350
10	3,773,618	59,291	7,206	58	18	4,324
11	2,694,673	42,235	5,139	41	13	3,080
12	3,076,872	47,760	5,837	467	14	3,483
1	3,034,774	47,660	5,793	47	14	3,476
2	3,454,930	54,259	6,596	53	16	3,957
3	3,511,199	55,168	6,705	54	16	4,023
4	4,029,378	63,309	7,694	62	19	4,617
5	1,809,543	20.758	1,582	0	0	0
6	1,773,306	20.343	1,550	0	0	0

NOx emission factor of 6 66g Kg of fuel oil used, from Walker et al. (1985 .

6.2.5 Effluent Treatment.

The primary function of the effluent treatment plant is the biological treatment of effluent from stock preparation, paper manufacture and the boiler plant. The effluent is adjusted for pH, using an acid or alkali, and passed through a series of primary settling tanks to remove solids. Chemicals are added to promote the coagulation of particulates (see Figure 6.1). The effluent is then passed through an aerated tank where bacteria brake down the dissolved organic matter in the effluent, absorbing other substances in the process, with nutrients added to feed the bacteria. The resulting mixture is passed into a secondary settling tank for removal of the bacterial matter as a sludge, using coagulants to promote settling. The remaining effluent is finally released via an outfall pipe to estuarine surface waters.

6.2.5.1 Process Emissions.

Direct emissions from effluent treatment take place to air and water. No data is available on the likely releases of CO_2 and other gases released to air. Direct emissions to water are measured using a limited number of parameters. Consistent measurements are only taken for pH, BOD/COD, and suspended solids. In addition, a regular survey has been carried out on the release of Schedule 5 substances, but these have almost entirely been below the level of detection or could not be linked to the constituents quoted in the material safety data sheets for the products used at the site. A theoretical estimate was, therefore, made of the quantity of each known product constituent emitted using a mass balance study (see section 3.6.3), with removal factors for the stock preparation and paper manufacture processes from sections 6.2.1 and 6.2.2. To estimate how much of each product constituent was retained by the effluent treatment plant, a Water Treatment Removal Factor (WTRF) was derived, based on past experience of the mill. This factor, set at 70%, was then used to estimate the amount of each chemical released to surface waters. The factor is valid for suspended solids, BOD and metals. Chlorine, however, is not readily attenuated by standard biological treatment and, therefore, has a WTRF of 0%. Those chemicals used in effluent treatment, similar to those used for cleaning within the mill, will have a PMRF of 0%, as they do not form part of the paper making process. The resulting emission estimates for those substances covered by the IEI and TEPI are given in Table 6.4.

Table 6.4- Emissions to Water from Company C (Kg).

Parameter	Pb	As	Sn	Cr	Ni	Zn	Hg	Co	NH^{4+}	Fe	Cu	PO_4^-	BOD	COD
Period														
7	0.089	0.032	0.19	0.047	0.0216	0.20	0.00114	0.0027	1.00	207.27	0.22	2.65	4,716	15,719
8	0.028	0.010	0.06	0.014	0.0063	0.06	0.00009	0.0008	0.09	16.35	0.07	0.21	1,876	6,253
9	0.059	0.022	0.12	0.052	0.0254	0.15	0.00051	0.0035	0.45	92.80	0.15	1.17	2,503	8,343
10	0.084	0.030	0.18	0.035	0.0150	0.18	0.00072	0.0017	0.63	131.85	0.21	1.64	2,302	7,673
11	0.090	0.032	0.19	0.032	0.0131	0.19	0.00069	0.0013	0.60	127.51	0.22	1.58	2,357	7,858
12	0.142	0.051	0.30	0.053	0.0219	0.30	0.00075	0.0023	0.65	135.53	0.39	1.86	2,761	9,205
1	0.064	0.023	0.13	0.011	0.0037	0.13	0.00086	0.0000	0.75	155.82	0.15	2.07	3,338	11,128
2	0.107	0.038	0.23	0.039	0.0163	0.23	0.00082	0.0017	0.71	148.36	0.37	1.94	3,587	11,956
3	0.074	0.027	0.16	0.042	0.0197	0.17	0.00087	0.0024	0.76	156.94	0.23	1.99	3,961	13,203
4	0.120	0.043	0.25	0.048	0.0209	0.26	0.00100	0.0022	0.87	182.00	0.30	2.30	4,726	15,754
5	0.079	0.028	0.17	0.034	0.0153	0.17	0.00086	0.0017	0.75	157.66	0.20	1.98	3,419	11,397
6	0.096	0.034	0.20	0.040	0.0175	0.21	0.00093	0.0019	0.81	169.41	0.32	2.14	3,588	11,960

Table 6.5 - Internal Transport Emissions from LPG for Company C (Kg).

	Period	7	8	9	10	11	12	1	2	3	4	5	6
Ener. Factor (MJ/ltr)	Usage(ltrs)	9,942	9,942	12,427	9,942	9,942	12,427	9,942	9,942	12,427	9,942	9,942	12,427
25.605	Usage(MJ)	254,552	254,552	318,190	254,552	254,552	318,190	254,552	254,552	318,190	254,552	254,552	318,190
Substance	Emi. Factor (g/MJ)												
CO_2	59.57	15,164	15,164	18,955	15,164	15,164	18,955	15,164	15,164	18,955	15,164	15,164	18,955
CO	0.67	171	171	213	171	171	213	171	171	213	171	171	213
HC	0.03	8	8	10	8	8	10	8	8	10	8	8	10
NOx	0.07	18	18	22	18	18	22	18	18	22	18	18	22

Emission factors from Gover et al. (1996).

Table 6.6 - Internal Transport Emissions from Diesel for Company C (Kg).

	Period	7	8	9	10	11	12	1	2	3	4	5	6
	Usage(ltrs)	2,100	2,354	3,053	3,073	2,459	2,381	3,080	2,701	2,400	3,464	2,865	2,440
Substance	Emission Factor(g/ltr)												
CO_2	2,592.23	5,444	6,101	7,915	7,966	6,373	6,172	7,983	7,002	6,221	8,979	7,426	6,325
CO	12.91	27	30	39	40	32	31	40	35	31	45	37	32
HC	3.20	7	8	10	10	8	8	10	9	8	11	9	8
NOx	13.50	28	32	41	41	33	32	42	36	32	47	39	33
PM	2.33	5	5	7	7	6	6	7	6	6	8	7	6
SO_2	0.87	2	2	3	3	2	2	3	2	2	3	2	2

Emission factors from Gover et al. (1996).

6.2.6 Distribution.

The fine paper manufactured at the site is distributed globally to customers and agents, using heavy goods vehicles and sea going freight carriers. The data for this function was not readily available for this site, so it was not possible to include the emissions from this function in the site total.

6.2.7 Site Parameters.

A number of parameters used by TEPI are relevant to all of the processes and are best covered as a whole for the site.

6.2.7.1 Internal Transport.

Internal transport covers those operations that use fossil fuels to drive transport and transfer systems, using forklift trucks. To estimate the mass emissions from this function, data has been collected on the quantity of LPG and diesel used. Emission factors from Gover et al. (1996) have been used to calculate the expected emissions from the two fuels (see Table 6.5 & Table 6.6). For diesel these relate directly to the amount of fuel used, whereas for LPG the energy content was firstly calculated from its calorific value.

6.2.7.2 Heat Losses.

Heat losses from the site were estimated for the boiler plant only, using an efficiency of 85% (see Table 6.7), assuming that all the energy in the steam is transferred as useful work.

Table 6.7 - Heat Losses from Company C (GJ).

Period	7	8	9	10	11	12	1	2	3	4	5	6
Energy In	157	13	370	45	152	714	62	70	42	48	33,032	32,371
Heat Loss	24	2	56	7	23	107	9	10	6	7	4,955	4,856

6.2.7.3 Land Area.

The area of land owned by the site covers 50,937m^2. It is assumed that all of this land is covered by the site's operations.

6.2.7.4 Electricity Use.

Electricity is the secondary source of energy for the site. Although the use of electricity has no direct environmental burden, it will be used to estimate the contribution of an indirect process on the company.

Table 6.8 - Electricity Use at Company C (KWh).

Period	7	8	9	10	11	12
Usage	2,845,000	1,093,000	2,695,000	3,147,000	2,382,000	2,460,000
Period	1	2	3	4	5	6
Usage	2,522,000	2,717,000	2,735,000	3,317,000	2,514,000	2,507,000

The usage figures used to calculate this contribution, from the emissions of a variety of electricity generators, are given in Table 6.8.

6.3 The Integrated Environmental Index.

The IEI is only calculated for those substances released via point-sources. Internal transport emissions will, therefore, not be included in the assessment. All releases are firstly tested for significance, as discussed in section 2.3.3. The required release rates have been calculated using the site running hours to give a monthly average. The release rates and significance limits for emissions to air are given in Table 6.10 and in Table 6.9 for water. Significant releases are shown in **bold** or underlined.

Table 6.9 - Water Release Rates & Limits for Company C (ug/s).

Parameter	Pb	As	Sn	Cr	Ni	Zn	Hg	NH^{4+}	Fe	Cu	BOD
Period											
7	**40.43**	14.58	**84.87**	21.37	9.80	**90.98**	**0.520**	**453.74**	**94,230**	**101.29**	2,143,860
8	36.54	13.17	**76.95**	18.48	8.25	**81.79**	0.120	**112.68**	**21,419**	**89.78**	2,457,879
9	30.29	11.09	**63.08**	**26.66**	12.96	**76.78**	0.261	**231.64**	**47,301**	**77.54**	1,275,693
10	36.32	12.97	**75.76**	14.84	6.45	**77.71**	0.309	**271.97**	**56,695**	**88.57**	989,787
11	**52.19**	18.65	**110.52**	18.37	7.61	**110.50**	0.402	**351.10**	**74,099**	**127.92**	1,369,960
12	**78.78**	28.21	**167.80**	**29.27**	12.16	**168.90**	0.414	**362.02**	**75,297**	**216.19**	1,534,146
1	36.35	12.84	**76.41**	6.49	2.12	**71.27**	**0.489**	**426.39**	**88,695**	**88.09**	1,900,286
2	**54.22**	19.34	**114.27**	19.60	8.24	**114.89**	0.413	**360.38**	**75,064**	**187.77**	1,814,841
3	37.95	13.70	**80.27**	21.64	10.08	**87.45**	0.446	**389.37**	**80,431**	**115.41**	2,029,911
4	**48.47**	17.30	**101.79**	19.40	8.47	**104.18**	0.405	**354.01**	**73,803**	**120.50**	1,916,545
5	**41.95**	14.97	**88.05**	18.08	8.11	**91.32**	0.457	**396.90**	**83,420**	**104.11**	1,809,108
6	**52.12**	18.60	**109.29**	21.59	9.55	**112.55**	**0.506**	**443.00**	**92,269**	**173.11**	1,954,269
Limit	39.80	39.80	15.92	23.88	47.76	63.68	0.464	43.06	1,592	7.96	N/A

Bold = Significant release for water quality.
Limits calculated for nominal flow rate of 0.796 m^3/s from HMIP (1995b).
Nominal flow rate from SEPA (1996c).

For those substances released at a significant rate during a given month, a more detailed assessment must be carried out, using the modelling techniques described in section 3.3.

Table 6.10 - Air Release Rates & Limits for Company C (g/s).

Parameter Period	Running Hours	SO_2	NO_x	Ni	Parts.
7	611	**23.80**	**4.25**	**0.007**	1.74
8	212	**22.90**	**4.04**	**0.007**	1.67
9	545	**23.41**	**4.30**	**0.007**	1.71
10	646	**25.50**	**4.50**	**0.008**	1.86
11	478	**24.54**	**4.40**	**0.007**	1.79
12	500	**26.53**	**5.06**	**0.008**	**1.94**
1	488	**27.13**	**4.80**	**0.008**	**1.98**
2	549	**27.45**	**4.86**	**0.008**	**2.00**
3	542	**28.27**	**5.99**	**0.008**	**2.06**
4	685	**25.67**	**4.53**	**0.008**	1.87
5	525	0.01	**17.70**	0.000	0.00
6	510	0.01	**17.86**	0.000	0.00
Air Limit		2.60	3.00	0.001	1.90
Land Limit		N/A	N/A	0.060	N/A

Bold Significant release for air quality.
Underlined Significant release for deposition to land.
Calculated for stack height of 48.8m from HMIP (1995b).

6.3.1 Emissions to Air.

For releases to air the ISCLT model combines meteorological and topographic data with technical data to predict the dispersion of significant releases from Table 6.10. The technical data for the site is given in Table 6.11.

Table 6.11 - Technical Data for Air Emissions from Company C.

Parameter	Value
Stack Height (m)	48.8
Exit Diameter (m)	2.4
Exit Velocity (m/s)	5.6
Exit Temperature (°C)	146
X Co-ordinate (m)	0
Y Co-ordinate (m)	0

Meteorological data from Leuchars was used (Meteorological Office 1995a), with topographic data derived from a local Ordnance Survey (1987c) map (see Table 6.12).

Using the above data the model was run for each substance in each month to predict the location with the maximum average annual concentration. Table 6.13 shows the results for significant releases from Company C. The table also shows the EQSs or EALs for the substances concerned. These are used to calculate the EQ for air (see Table 6.14), as described in section 2.3.3.

In the BPEO methodology (HMIP 1995b) the EQS for NOx is given, not as an annual average, but as a 98th percentile. As the meteorological data required to calculate 98th percentile values was not available, the annual average limit value for NOx was used as a substitute.

Table 6.12 - Polar Grid Elevation Heights for Company C (m).

Distance (m)	50	250	500	750	1,000	2,000	3,000	4,000	5,000
Direction (°)									
45	10	10	10	10	10	10	10	10	10
90	10	0	0	0	0	0	0	0	0
135	10	0	10	10	10	20	46	46	20
180	10	15	15	15	15	46	92	76	122
225	10	15	22	26	30	30	15	15	15
270	10	15	15	15	15	15	22	61	122
315	10	10	10	10	15	22	46	122	76
360	10	10	10	10	10	15	15	15	30
Base Height									10

Polar grid co-ordinates centres on (0 , 0).
From Ordnance Survey (1987c).

6.3.2 Emissions to Water.

For emissions to estuarine surface waters a mass balance model was used to estimate the dispersion of significant releases from Table 6.9. The model predicts concentrations at the outfall, and at points up and downstream of it, using data on the dimensions, discharge, and salinity of those points in the estuary, as described in section 3.3.3.

Salinity data was not readily available for the local estuary, but was calculated

Table 6.13 - Predicted Concentrations in Air for Company C (ug/m).

	Period	7	8	9	10	11	12	1	2	3	4	5	6
Parameter	EQS / EAL (ug/m^3)												
SO_2	80	2.514035	2.418857	2.472837	2.693194	2.592734	2.802950	2.865803	2.900029	2.986757	2.711998	-	-
NOx	50	-	-	-	0.327466	-	0.342714	0.348535	0.352704	0.363166	0.329785	-	-
Ni	0.2	0.000739	0.000739	0.000739	0.000845	0.000739	0.000845	0.000845	0.000845	0.000845	0.000845	-	-
Parts	80	-	-	-	-	-	0.204406	0.208948	0.211484	0.217822	-	-	-

Table 6.14 - Environmental Quotients ($EQ_{(S)}$) and $EQ_{(Air)}$ for Company C.

Period	7	8	9	10	11	12	1	2	3	4	5	6
Parameter												
SO_2	0.031425	0.030236	0.030910	0.033665	0.032409	0.035037	0.035823	0.036250	0.037334	0.033900	0.000000	0.000000
NOx	0.000000	0.000000	0.000000	0.006549	0.000000	0.006854	0.006971	0.007054	0.007263	0.006596	0.000000	0.000000
Ni	0.003695	0.003695	0.003695	0.004225	0.003695	0.004225	0.004225	0.004225	0.004225	0.004225	0.000000	0.000000
Parts	0.000000	0.000000	0.000000	0.000000	0.000000	0.002555	0.002612	0.002644	0.002723	0.000000	0.000000	0.000000
$EQ_{(Air)}$	0.035120	0.033931	0.034605	0.044439	0.036104	0.048671	0.049630	0.050173	0.051546	0.044721	0.000000	0.000000

from water temperature and conductivity data (SEPA 1996i) using an algorithm based on the practical salinity scale (Lewis 1980).

Table 6.15 - Physical Data for Estuary at Company C.

Parameter	Upstream	Outfall	Downstream
Estuary Salinity (ppt) *	25.36	20.49	32.63
River Discharge (m^3/s) †	3.9	4.4	4.4
Cross-Sectional Area (m^2) ¶	111.25	248.61	657.41
Distance to Estuary Mouth #(m)	7,200	7,000	6,000
Nominal Flow Rate (m^3/s) †			0.796
Sea Water Salinity (ppt) ‡			33.75

From SEPA (1996i). † From SEPA (1996c). ¶ From Jarvis (1996).
From North Sea Task Force (1993). # From Ordnance Survey (1987c).

The salinity data, along with the other data required for the local estuary is given in Table 6.15. The river flow data were obtained from SEPA (1996c) and represent the long-term average. The cross-sectional area at the three measurement points was derived using topographical data from Jarvis (1996) and represent the average of the areas at the high and low water level. The distance to the estuary mouth was estimated using a pesometer and an Ordinance Survey (1987c) map. Sea water salinity data was obtained from a North Sea Task Force (1993) study on the state of the North Sea.

The above data was used to calculate the predicted environmental concentrations shown in Table 6.16. Concentrations have also been calculated for BOD, which presently has no EQS or EAL within the IEI for estuarine releases, using the EQS for riverine releases. The results will be used later as BOD is known to be a major environmental burden from the site. The table shows the EQSs or EALs for each substances, which are used to calculate the EQ for water in Table 6.17. Separate EQs have been worked out for BOD.

Table 6.16 - Predicted Concentrations in Water for Company C (mg/m^3).

Period	EQS / EAL	7	8	9	10	11	12	1	2	3	4	5	6
Param.	(mg/m^3)												
NH^{4+}	27	0.040510	0.010060	0.020680	0.024281	0.031346	0.032321	0.038068	0.032175	0.034762	0.031606	0.035435	0.039551
BOD	3,000	188.795754	216.450058	112.342330	87.164312	120.643842	135.102658	167.346315	159.821723	178.761605	168.778098	159.316841	172.100251
Cr	15	-	-	0.002380	-	-	0.002613	-	-	-	-	-	-
Cu	5	0.009043	0.008016	0.006923	0.007907	0.011420	0.019302	0.007864	0.016764	0.010304	0.010758	0.009295	0.015455
Fe	1,000	8.412777	1.912292	4.223008	5.061722	6.615523	6.722487	7.918682	6.701655	7.180819	6.589116	7.447677	8.237740
Pb	25	0.003610	-	-	-	0.004660	0.007033	-	0.004841	-	0.004328	0.003745	0.004653
Hg	0.3	0.000046	-	-	-	-	-	0.000044	-	-	-	-	0.000045
Sn	10	0.007577	0.006870	0.005631	0.006764	0.009867	0.014981	0.006822	0.010202	0.007166	0.009087	0.007861	0.009758
Zn	40	0.008123	0.007302	0.006854	0.006938	0.009865	0.015079	0.006363	0.010257	0.007808	0.009301	0.008153	0.010049

Table 6.17 - Environmental Quotients (EQ$_s$) and EQ$_{Water}$ for Company C.

Period Parameter	7	8	9	10	11	12	1	2	3	4	5	6
NH^{4+}	0.00150	0.00037	0.00077	0.00090	0.00116	0.00120	0.00141	0.00119	0.00129	0.00117	0.00131	0.00146
Cr	0.00000	0.00000	0.00016	0.00000	0.00000	0.00017	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cu	0.00181	0.00160	0.00138	0.00158	0.00228	0.00386	0.00157	0.00335	0.00206	0.00215	0.00186	0.00309
Fe	0.00841	0.00191	0.00422	0.00506	0.00662	0.00672	0.00792	0.00670	0.00718	0.00659	0.00745	0.00824
Pb	0.00014	0.00000	0.00000	0.00000	0.00019	0.00028	0.00000	0.00019	0.00000	0.00017	0.00015	0.00019
Hg	0.00015	0.00000	0.00000	0.00000	0.00000	0.00000	0.00015	0.00000	0.00000	0.00000	0.00000	0.00015
Sn	0.00076	0.00069	0.00056	0.00068	0.00099	0.00150	0.00068	0.00102	0.00072	0.00091	0.00079	0.00098
Zn	0.00020	0.00018	0.00017	0.00017	0.00025	0.00038	0.00016	0.00026	0.00020	0.00023	0.00020	0.00025
EQ$_{(Water)}$	0.01298	0.00476	0.00727	0.00839	0.01148	0.01411	0.01189	0.01272	0.01144	0.01123	0.01176	0.01436
BOD †	0.06293	0.07215	0.03745	0.02905	0.04021	0.04503	0.05578	0.05327	0.05959	0.05626	0.05311	0.05737
EQ$_{(Water)}$ †	0.07591	0.07691	0.04471	0.03745	0.05169	0.05914	0.06767	0.06599	0.07103	0.06749	0.06486	0.07172

† EQ$_{(BOD)}$ and EQ$_{(Water)}$ calculated using EQS$_{(BOD)}$ for riverine surface waters.

6.3.3 Emissions to Land.

Company C has no significant direct or indirect releases to land (see Table 6.10). The EQ for land is, therefore, zero.

6.3.4 The Integrated Environmental Index.

The EQs for air, water and land and the resulting IEI for Company C are shown in Table 6.18. A separate calculation has been made to include the BOD parameter.

Table 6.18 - $EQ_{(Air)}$, $EQ_{(Water)}$, $EQ_{(Land)}$ and the IEI for Company C.

Period	$EQ_{(Air)}$	$EQ_{(Water)}$	$EQ_{(Water)}$ †	$EQ_{(Land)}$	IEI	IEI †
7	0.0351	0.0130	0.0759	0.0000	0.0481	0.1110
8	0.0339	0.0048	0.0769	0.0000	0.0387	0.1108
9	0.0346	0.0073	0.0447	0.0000	0.0419	0.0793
10	0.0444	0.0084	0.0374	0.0000	0.0528	0.0819
11	0.0361	0.0115	0.0517	0.0000	0.0476	0.0878
12	0.0487	0.0141	0.0591	0.0000	0.0628	0.1078
1	0.0496	0.0119	0.0677	0.0000	0.0615	0.1173
2	0.0502	0.0127	0.0660	0.0000	0.0629	0.1162
3	0.0515	0.0114	0.0710	0.0000	0.0630	0.1226
4	0.0447	0.0112	0.0675	0.0000	0.0559	0.1122
5	0.0000	0.0118	0.0649	0.0000	0.0118	0.0649
6	0.0000	0.0144	0.0717	0.0000	0.0144	0.0717

† Including BOD parameter.

6.4 The Total Environmental Potency Index.

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 6.3 - Table 6.7. Each of the substances covered by the TEPI is allocated a series of potency factors which describe its contribution to different environmental potency categories, as discussed in section 3.4.. The category totals and TEPI from these emissions are given in Table 6.19. In order to assess the effect of electricity use on the site's total potency in section 11.3.3, the usage data in Table 6.7 has been used to calculate the TEPI for electricity, based on the average UK generation mix (see Table 6.20). This data has not been included in the site totals used for the comparative study.

Table 6.19 - Category Totals and TEPI for Company C.

Period	7	8	9	10	11	12	1	2	3	4	5	6
Cat.												
GWP	3,358,806	1,133,545	2,968,366	3,796,748	2,716,209	3,101,999	3,057,921	3,477,095	3,536,375	4,053,521	1,832,133	1,798,585
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	414,074	138,234	363,275	468,965	334,083	377,799	376,982	429,179	436,358	500,765	479	478
AETP	2,066	648	1,759	2,228	1,633	1,888	1,800	2,093	2,118	2,439	199	230
TETP	26,094,677	8,709,093	22,889,985	29,550,552	21,051,667	23,804,994	23,756,146	27,043,945	27,497,244	31,555,267	7,085	7,616
POCP	2,703	911	2,377	3,062	2,184	2,471	2,464	2,802	2,850	3,269	59	59
AP	56,840	19,000	49,893	64,379	45,870	51,886	51,760	58,916	59,901	68,743	1,170	1,146
NP	1,183	420	921	1,115	849	970	1,008	1,130	1,171	1,358	466	474
WH	24	2	56	7	23	107	9	10	6	7	4,955	4,856
LA	50,937	50,937	50,937	50,937	50,937	50,937	50,937	50,937	50,937	50,937	50,937	50,937
TEPI	29,981,310	10,052,790	26,327,569	33,937,992	24,203,456	27,393,051	27,299,026	31,066,107	31,586,961	36,236,307	1,897,482	1,864,381

Table 6.20 - Category Totals and TEPI for Electricity Used at Company C (UK Average).

Period Cat.	7	8	9	10	11	12	1	2	3	4	5	6
GWP	1,852,247.810	711,601.707	1,754,589.753	2,048,866 031	1,550,809 942	1,601,592 131	1 641,957.461	1,768,912.935	1,780.631.902	2,159,545.162	1,636,749.032	1,632,191.656
ODP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HTP	2,568.348	986.715	2,432.935	2,840.982	2,150.371	2,220.786	2,276.757	2,452.795	2,469.045	2,994.450	2,269.535	2,263.216
AETP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TETP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
POCP	588.503	226.093	557.475	650.973	492.729	508.864	521.689	562.026	565.749	686.139	520.034	518.586
AP	11,043.858	4,242.860	10,461.580	12,216.176	9,246.562	9,549.346	9,790.021	10,546.981	10,616.854	12,876.090	9,758.966	9,731.793
NP	703.872	270.415	666.761	778.589	589.323	608.620	623.960	672.204	676.657	820.648	621.980	620.249
WH	20.533	7.888	19.451	22.713	17.192	17.754	18.202	19.609	19.739	23.940	18.144	18.094
LA	1.061	0.408	1.005	1.174	0.888	0.917	0.941	1.013	1.020	1.237	0.938	0.935
TEPI	1,867,173.985	717,336.086	1,768,728.960	2,065,376.637	1,563,307.006	1,614,498.420	1,655,189.030	1,783,167.564	1,794,980.967	2,176,947.666	1,649,938.629	1,645,344.528

CHAPTER SEVEN

Company D

Paperboard

7.1 The Company.

Company D is a paperboard manufacturer taking part as a grey box site. The company forms part of an independent UK paper products group, making a single type of paperboard for use in the graphic arts. The site is subject to IPC for its steam generation plant, but has been granted an exception for the actual papermaking process. The site is accredited to BS7750 and the group as a whole reports on the environment as part of its annual report, which is publicly available. The company employs 200 people, from 1,000 within the group. Environmental matters at a site level are the responsibility of the technical manager, with additional input from an environmental consultant retained by the group.

7.2 The Paper Making Processes & Emissions.

The paper making process has been divided into six sub-systems to help understand how they work, gather data and estimate emissions. These are: paper preparation, paper manufacture, paper finishing, distribution, boiler plant and effluent treatment (Figure 7.1). The processes and emissions associated with these sub-systems are discussed below.

7.2.1 Paper Preparation.

The paper preparation sub-system converts the input materials into a form suitable for paper manufacture. This primarily entails mixing the fibre and other materials with water to obtain a final composition of 1% fibre (Figure 7.1). The fibre materials are firstly mixed with water, and possibly bleach, in a pulper to obtain a mixture of 5% fibre. The pulped fibre is then passed through refiners to a mixing chest, where it is combined with more water, as well as sizing,

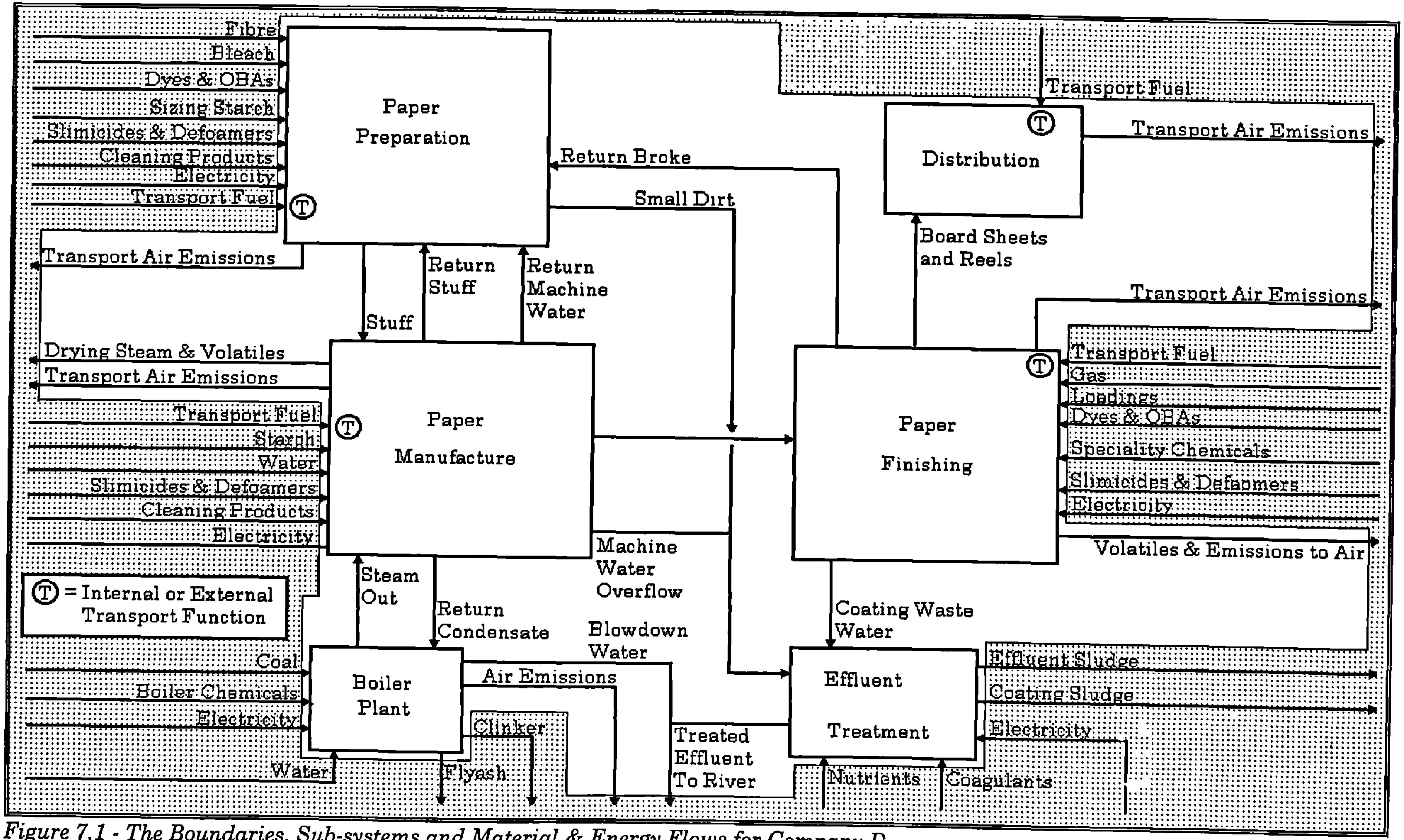


Figure 7.1 - The Boundaries, Sub-systems and Material & Energy Flows for Company D.

slimicides, defoamers and return stuff to a consistency of 3%. This mixture is then referred to as stuff. Defoamers and slimicides are added to prevent frothing and biological growth in the process. Cleaning products are also used, but only when the process is shut down. These materials do, therefore, not end up in the paper itself. Some raw materials are transported to the process using fork-lift trucks, with the size and starch fed in by pipe. The stuff is finally passed through a set of cyclone filters, which remove any fine dirt, before being mixed with the return machine water to a final consistency of 1% fibre and passed onto paper manufacture.

7.2.1.1 Process Emissions.

Direct emissions from paper preparation consist releases to air from the fork-lift trucks, which are covered in section 7.2.7.1. Indirect emissions occur via the paper manufacture and effluent treatment sub-systems, before being released in the effluent. As the number of effluent parameters measured are limited, the remainder have been estimated using a mass balance based on the company's usage figures in section 7.2.5. For those materials used in paper manufacture, removal factors have been calculated in section 7.2.2. Any other materials will pass straight to the effluent treatment plant.

7.2.2 Paper Manufacture.

The paper manufacture sub-system contains the processes associated with the making of the paper itself. This process has changed little since it was started in 1803 (Watson 1987). The stuff from paper preparation is passed into the head-box of two paper machines. The head-box distributes the stuff equally across a synthetic mesh called the "wire" (see Figure 6.2). The wire passes at constant speed from under the head-box to obtain a set grammage of paper. Most of the water passes through the paper and wire into the machine pit below (see Figure 6.2). This water is returned to the head-box and mixed with the incoming stuff. Excess water is stored for use in pulping or removed to effluent treatment as machine water overflow. The edges of the paper are trimmed using high pressure jets, with the excess stuff being fed back to the mixing chest for re-use. Additional water is removed from the paper through a series of vacuum boxes over which the wire passes, with a final vacuum box contained in the couch roll at the end of the wire. From the couch roll the two paper streams are combined in a two-wire pressing machine, where the paper is pressed between two sets of felt sheets which absorb further water. This water is extracted from the felt and passed to effluent treatment as machine water overflow. The paper is then dried in two sections by being passed over a set of steam filled drums, passing through a starch size press in the middle. Moisture from the paper is vented to air via a heat exchanger, with steam from the drying rolls going back to the boiler plant as return condensate. The paper is then passed onto paper finishing for coating. The paper machines are run by a series of computers which control pumps, motors and valves, all running on electricity. Cleaning products are used to service the machines and pipes during stoppages and are not incorporated into the papermaking process, passing directly to effluent treatment as machine water overflow.

7.2.2.1 Process Emissions.

Direct emissions from this sub-system consist of releases to air from fork-lift trucks (see section 7.2.7.1) and the infra-red dryers, with additional emissions of water vapour and volatiles. No monthly data is available on the release of volatile organic compounds from the dryers, so it is assumed that all constituents of the stuff either remain in the paper or are removed to effluent treatment. Water vapour emissions have been estimated using the average amount of water in the paper on entry and exit to the drying section. It is also assumed that all the steam supplied to the drying drums is returned to the boiler plant as condensate.

Indirect emissions occur via the effluent treatment plant and have been estimated using a mass balance for the site in section 7.2.5. None of the materials used in paper preparation are removed, but this is not the case here. To estimate how much of each ingredient and its constituents has been incorporated into the paper, material usage data has been used to estimate a Paper Making Removal Factor (PMRF), according to Equation 7.1.

Equation 7.1- Calculation of the Paper Making Removal Factor for Company D.

$$\begin{aligned}\mathrm{PMRF} &= \frac{\text{Dry Weight of Paper Manufactured}}{\text{Dry Weight of Products In}}\\ &= \frac{37{,}425{,}800\ \text{Tonnes}}{43{,}808{,}732\ \text{Tonnes}}\\ &= 85.43\%\end{aligned}$$

This factor was then used to estimate the amount of each chemical used in paper preparation and manufacture which remains for effluent treatment. Those products not used in the paper making process, such as cleaning materials, will have a PMRF of 0%. The final emissions from the effluent plant are given in section 7.2.5.

7.2.3 Paper Finishing.

The paper finishing sub-system coats the dried board before it is passed through a final set of dryers and a calendars. The coating is made up of a mixture of loadings, pigments and synthetic latex, as well as slimicides and defoamers (see Figure 7.1). The dried board is pre-coated, dried and passed through the main coaters. The board then passes under gas-fired infra-red dryers and moves on to calendars where the board is pressed into its final specification. The board is then checked for moisture and ash content before being reeled up. Once a reel has been filled with board it is removed to be cut to size or into sheets. The final product is then packed for dispatch and stored. Any reject board is returned to paper preparation as return broke. Transport of the reels and finished product takes place using fork-lift trucks.

7.2.3.1 Process Emissions.

Direct emissions consist of releases to air from the fork-lift trucks (see section 7.2.7.1) and the gas-fired dryers. The gas dryer emissions were worked out using the emission factors in section 6.2.4 and gas usage data (see Table 7.1).

Table 7.1 - Gas Dryer Emissions to Air from Company D (Kg).

Parameter	CO_2	SO_2	NO_x
Period			
7	108,748.273	1.005	95.049
8	89,371.865	0.826	78.113
9	103,327.781	0.955	90.311
10	110,946.207	1.025	96.970
11	98,743.412	0.912	86.304
12	80,109.809	0.740	70.018
1	95,471.085	0.882	83.444
2	103,843.515	0.959	90.762
3	100,840.563	0.932	88.137
4	114,400.192	1.057	99.989
5	83,346.054	0.770	72.846
6	78,389.038	0.724	68.514

Some volatiles and water will be released when the board is dried. However, as these are not regularly sampled, it has been assumed that these emissions are negligible.

Indirect emissions consist of waste coating material, which is passed onto effluent treatment. These releases have been estimated using a mass balance in section 7.2.5, and have been included in the calculation of the PMRF for the materials used at the site, in section 7.2.2. Again any cleaning products used at this stage will pass straight through the system to effluent treatment.

7.2.4 Boiler Plant.

The boiler plant provides steam for the paper manufacture system to dry the paper. This steam is generated using coal in two boilers. The exhaust gases from the boilers are released to air through a single stack. River water, treated to prevent corrosion within the boiler, is used to generate the steam. This water is used to top up the return condensate from the dryers which is released as blowdown water. The boilers are operated by electrical control equipment, with no internal transport operations.

7.2.4.1 Process Emissions.

Direct emissions from the boiler plant consist of the combustion products from the coal burnt. Data on the emissions of SO_2 and NO_x were available from the company and are given in Table 7.3. The remaining parameters have been estimated using data on the constituents of coal ash to derive emission factors.

Table 7.2 - Composition Data for Coal CO_2 emissions at Company D.

Coal Composition					
Parameter	C	Other	Sulphur	Ash	Water
Composition (%)	47.00	28.90	0.57	4.50	19.60
Stack Ash Composition					
Parameter	CHN	Ash	Water	-	
Av. Composition (%)	69.20	29.00	1.80	-	
Relative to Ash	2.386	1	0.062	-	
Emission Factors					
Parameter	Ash	Ash CHN	Ash Water	CO_2	
Factor (Kg/Kg)	0.0450	0.1074	0.0028	2.3124	

Table 7.3 - Coal Combustion Emissions to Air from Company D (Kg).

Period Param	7	8	9	10	11	12	1	2	3	4	5	6
CO_2	3,907,371.3	3,684,803.1	4,005,648.1	4,428,238.5	3,509,061.0	2,659,255 5	3,584,213.9	3,521,779.2	3,555,309.0	3,972,696.4	3,370,317.3	3,327,537.9
SO_2	31,463.0	29,671.0	32,254.0	35,657.0	21,134 0	21,413 0	28,861.0	28,358.0	28,628.0	31,989.0	27,139.0	26,794.0
NO_x	10,307.0	9,720.0	10,567.0	11,682.0	9,257.0	7,015 0	9,455.0	9,290.0	9,379.0	10,480.0	8,891.0	8,778.0
Al_2O_3	887.8	694.4	717.2	933.8	682.0	621 9	859.2	682.9	685.3	893.5	672.2	669.2
Fe_2O_3	331.1	259.0	267.5	348.3	254.3	231.9	320.4	254.7	255.6	333.2	250.7	249.6
CaO	85.0	66.5	68.6	89.4	65.3	59.5	82.2	65.4	65.6	85.5	64.3	64.0
Ni	16.3	12.8	13.2	17.2	12.5	11.4	15.8	12.6	12.6	16.4	12.4	12.3
Mn	12.2	9.5	9.8	12.8	9.3	8.5	11.8	9.4	9.4	12.2	9.2	9.2
Be	0.4	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.3
Zn	2.2	1.7	1.8	2.3	1.7	1.6	2.1	1.7	1.7	2.2	1.7	1.7
Cu	5.0	3.9	4.1	5.3	3.9	3.5	4.9	3.9	3.9	5.1	3.8	3.8
Co	2.6	2.1	2.1	2.8	2.0	1.8	2.5	2.0	2.0	2.6	2.0	2.0
Ba	9.6	7.5	7.8	10.1	7.4	6.7	9.3	7.4	7.4	9.7	7.3	7.2
Cr	22.0	17.2	17.8	23.2	16.9	15.4	21.3	17.0	17.0	22.2	16.7	16.6
V	14.2	11.1	11.5	14.9	10.9	9.9	13.7	10.9	10.9	14.3	10.7	10.7
Parts	10,426.5	8,156.2	8,422.9	10,967.7	8,010.1	7,303.7	10,090.7	8,020.6	8,048.5	10,494.3	7,894.7	7,859.2

CO_2 emissions were estimated using carbon content data for the coal (see Table 7.2), minus that which remains in the final ash, assuming the full stoichiometric combustion of carbon.

Particulates, and the substances contained therein, were more difficult to estimate, as not all the material is released to air and monthly data was not available.

Table 7.4 - Ash Constituents in ash and fuel for Coal at Company D (%).

Constituent	As Fuel	As Ash
SiO_2	2.254%	50.096%
Al_2O_3	1.321%	29.360%
Fe_2O_3	0.493%	10.949%
TiO_2	0.061%	1.357%
CaO	0.126%	2.810%
MgO	0.035%	0.775%
Na_2O	0.004%	0.097%
K_2O	0.065%	1.453%
Ni	0.024%	0.540%
Mn	0.018%	0.402%
V	0.021%	0.469%
Be	0.001%	0.013%
Zn	0.003%	0.073%
Cu	0.008%	0.167%
Co	0.004%	0.087%
Sr	0.014%	0.304%
Ba	0.014%	0.318%
Cr	0.033%	0.729%
Total	4.50%	100.000%

Flow Rate (m^3/hr)	
Min	Max
20,702	24,870
Concentration(mg/m^3)	252

An estimate was calculated using data on the range of flow rates, and a sample of the particulate concentration in the stack (see Table 7.2). The flow rates were related to the amount of coal used to estimate particulate emissions, which were then broken down into their constituent parts using the data given in Table 7.2 (Watson 1995). The remaining parameters covered by the IEI and TEPI are given in Table 7.3.

7.2.5 Effluent Treatment.

The primary function of the effluent treatment plant is the biological treatment of effluent from paper preparation and manufacture, and the boiler plant. The effluent is passed through a series of primary settling tanks to remove solids. Chemicals are added to promote the coagulation of particulates (see Figure 7.1). The effluent is then passed through an aerated tank where bacteria break down the dissolved organic matter in the effluent, absorbing other substances in the process. Nutrients are added to feed the bacteria. The resultant mixture is then passed into a secondary settling tank for removal of the bacterial matter as a sludge, using coagulants to promote settling. The remaining effluent is finally released via an outfall pipe to riverine surface waters.

7.2.5.1 Process Emissions.

Direct emissions from effluent treatment take place to air and water. No data is available, however, on the releases of CO_2 and other gases that would be released to air. Direct emissions to water are measured using a limited number of parameters. Consistent measurements are only taken for pH, BOD/COD, and suspended solids. In addition a regular survey has been carried out on the releases of Schedule 5 substances, but these have almost entirely been below the level of detection or could not be linked to the constituents quoted in the material safety data sheets for the products used at the site. A theoretical estimate was, therefore, calculated for the quantity of each known product constituent emitted, using a mass balance study (see section 3.6.3), with removal factors for the paper preparation and manufacture processes from sections 7.2.1. and 7.2.2. To take account of the effluent treatment plant a Water Treatment Removal Factor (WTRF) of 70%, based on past experience of the mill, was used. This factor is valid

Table 7.5 - Emissions to Water from Company D (Kg).

Param.	Hg	Cd	Ni	Zn	Pb	As	Cr	Sn	Fe	Cu	NH^{4+}	PO_{4-}	BOD	COD	S.S.
Period															
7	0.00002	0.009	0.024	0.686	0.307	0.114	0.143	0.628	0.072	0.933	0.046	0.122	1,726.750	1,356.066	6,149.391
8	0.00020	0.009	0.019	0.520	0.225	0.085	0.125	0.453	0.072	0.802	0.046	0.122	1,335.032	884.575	4,006.249
9	0.00016	0.008	0.019	0.534	0.235	0.088	0.119	0.478	0.061	0.706	0.046	0.122	1,337.216	887.204	4,018.198
10	0.00016	0.008	0.021	0.611	0.273	0.101	0.127	0.558	0.091	0.857	0.046	0.122	1,272.163	808.903	3,662.288
11	0.00015	0.007	0.017	0.492	0.219	0.081	0.105	0.446	0.085	0.696	0.046	0.122	1,294.339	855.307	3,873.212
12	0.00011	0.005	0.013	0.375	0.166	0.062	0.083	0.337	0.052	0.486	0.046	0.122	1,503.348	1,306.102	5,922.280
1	0.00017	0.007	0.016	0.446	0.195	0.073	0.103	0.395	0.066	0.585	0.046	0.122	1,330.560	1,112.000	5,040.000
2	0.00021	0.008	0.019	0.545	0.240	0.090	0.122	0.486	0.085	0.733	0.046	0.122	1,499.837	1,303.059	5,908.448
3	0.00014	0.007	0.019	0.540	0.242	0.090	0.112	0.494	0.015	0.763	0.046	0.122	1,733.424	1,678.843	7,616.560
4	0.00016	0.008	0.021	0.598	0.267	0.099	0.126	0.546	0.054	0.742	0.046	0.122	1,290.643	981.938	4,448.808
5	0.00001	0.008	0.020	0.552	0.242	0.091	0.126	0.490	0.061	0.764	0.046	0.122	1,458.442	1,121.339	5,082.448
6	0.00001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.042	0.152	0.046	0.122	1,994.916	900.912	4,080.510

for suspended solids, BOD and metals. Chlorine, however, is not readily attenuated by standard biological treatment and, therefore, has a WTRF of 0%. Those chemicals used in effluent treatment, similar to those used for cleaning within the mill, will have a PMRF of 0%, as they do not form part of the papermaking process. The resulting emission estimates for those substances covered by the IEI and TEPI are given in Table 7.5.

7.2.6 Distribution.

The fine paper manufactured at the site is distributed globally to customers and agents, using heavy goods vehicles and sea going freight carriers.

7.2.6.1 Process Emissions.

Direct emissions occur primarily to air from this function. However, no data was available for these emissions. Data on the number of trips made to each client per month was, therefore, used to estimate expected emissions from road and sea distribution separately. The distance to each client was calculated using a route planner for distribution by road and a pesometer and atlas for distribution by sea. For road distribution this data was combined with emissions factors from Gover et al. (1996) to estimate the emission of six parameters, according to Equation 7.2.

Equation 7.2 - Road Distribution Emissions Calculation.

$$Q_{(a)} = \sum EF_{(a)} * Km_{(i)} * N_{(i)},$$

where,
$Q_{(a)}$ = Quantity emitted in kg of parameter, a.
$EF_{(a)}$ = Emission factor for parameter, a, in g/km.
$Km_{(i)}$ = Distance travelled to destination, i.
$N_{(i)}$ = Number of trips made to destination, i.
For all destinations, i = 1 ...n and parameters, a = 1 ...z.

For sea distribution this data was combined with emissions factors from

Table 7.6 - Road Distribution Emissions to Air from Company D (Kg).

Period		7	8	9	10	11	12	1	2	3	4	5	6
Distance (km)		88,173	104,994	115,392	157 371	128 639	55 545	153,069	223,535	221,150	243,263	197,939	155,697
Parameter	Emission Factor (g/km)												
CO_2	853	75,212	89,560	98,429	134,237	109,729	47,380	130 568	190,675	188,641	207,503	168,842	132,810
CO	3.92	346	412	452	617	504	218	600	876	867	954	776	610
N_2O	13.06	1,152	1,371	1,507	2,055	1,680	725	1,999	2,919	2,888	3.177	2,585	2,033
SO_2	0.28	25	29	32	44	36	16	43	63	62	68	55	44
PM	1.07	94	112	123	168	138	59	164	239	237	260	212	167
VOC	0.45	40	47	52	71	58	25	69	101	100	109	89	70

Emission Factors from Gover et al. (1996).

Table 7.7 - Sea Distribution Emissions to Air from Company D (Kg).

Period		7	8	9	10	11	12	1	2	3	4	5	6
Kg.Km ($x10^6$)		3,769	4,906	5,232	3,019	5,289	5,054	5,035	3,893	4,144	4,719	2,303	3,484
Parameter	Emission Factor (g/km.kg)												
Air Releases													
CO_2	0.0000095000	35.809	46.608	49.705	28.677	50.248	48.013	47.834	36.980	39.366	44.832	21.878	33.098
CO	0.0000000300	0.113	0.147	0.157	0.091	0.159	0.152	0.151	0.117	0.124	0.142	0.069	0.105
N_2O	0.0000000160	0.060	0.078	0.084	0.048	0.085	0.081	0.081	0.062	0.066	0.076	0.037	0.056
SO_2	0.0000000250	0.094	0.123	0.131	0.075	0.132	0.126	0.126	0.097	0.104	0.118	0.058	0.087
PM	0.0000000100	0.038	0.049	0.052	0.030	0.053	0.051	0.050	0.039	0.041	0.047	0.023	0.035
Pb	0.0000000000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VOC	0.0000000018	0.007	0.009	0.009	0.005	0.010	0.009	0.009	0.007	0.007	0.008	0.004	0.006
Water Releases													
Cu	0.00000000003	0.00011	0.00015	0.00016	0.00009	0.00016	0.00015	0.00015	0.00012	0.00012	0.00014	0.00007	0.00010
Sn	0.00000000003	0.00011	0.00015	0.00016	0.00009	0.00016	0.00015	0.00015	0.00012	0.00012	0.00014	0.00007	0.00010

Emission Factors from BMI et al. (1996).

BMI et al. (1996) to estimate the emission of nine parameters, according to Equation 7.3. The total monthly emissions from the distribution of paperboard covered by the TEPI are given in Table 7.6 and

Table 7.7.

Equation 7.3 - Sea Distribution Emissions Calculation.

$$Q_{(a)} = \Sigma EF_{(a)} * Km.Kg_{(i)} * N_{(i)},$$

where, $Q_{(a)}$ = Quantity emitted in kg for parameter, a.
$EF_{(a)}$ = Emission factor for parameter, a, in g/kg.km.
$Km.Kg_{(i)}$ = Distance*weight travelled to destination, i.
$N_{(i)}$ = Number of trips made to destination, i.
For all destinations, i = 1 ...n and parameters, a = 1 ...z

7.2.7 Site Parameters.

A number of parameters used by TEPI are relevant to all of the processes and are best covered as a whole for the site.

7.2.7.1 Internal Transport.

Internal transport covers those operations that use fossil fuels to drive transport and transfer systems at the site, normally by way of forklift trucks. To estimate the mass emissions from this function, data has been collected on the quantity of LPG and diesel used. Emission factors from Gover et al. (1996) have been used to calculate the expected emissions from the two fuels (see Table 7.8 & Table 7.9). For diesel these relate directly to the amount of fuel used, whereas for LPG the energy content was firstly calculated from its calorific value.

7.2.7.2 Heat Losses.

Heat losses from the site were estimated for the boiler plant only, using an efficiency of 85% (see Table 7.10). It is assumed that all the energy in the steam

Table 7.8 - Internal Transport Emissions to Air from Company D for LPG (Kg).

Period		7	8	9	10	11	12	1	2	3	4	5	6
Calorific Value (MJ/ltr)	Usage (ltrs)	5,312	4,585	5,168	3,388	5,037	3,770	2,676	3,444	3,272	3,117	4,143	3,480
25.605	(MJ)	136,013	117,398	132,326	86,749	128,972	96,530	68,519	88,183	83,779	79,810	106,081	89,105
Parameter	Em. Fact (g/MJ)												
CO_2	59.57	8,102	6,993	7,883	5,168	7,683	5,750	4,082	5,253	4,991	4,754	6,319	5,308
CO	0.67	91	79	89	58	86	65	46	59	56	53	71	60
VOC	0.03	4	4	4	3	4	3	2	3	3	2	3	3
NO_x	0.07	10	8	9	6	9	7	5	6	6	6	7	6

Emission Factors from Gover et al. (1996).

Table 7.9 - Internal Transport Emissions to Air from Company D for Diesel (Kg).

Period		7	8	9	10	11	12	1	2	3	4	5	6
Usage (ltrs)		473	378	378	473	378	378	473	378	378	473	378	378
Parameter	Em. Fact (g/ltr)												
CO_2	2,592.23	1,226.32	981.06	981.06	1,226.32	981.06	981.06	1,226.32	981.06	981.06	1,226.32	981.06	981.06
CO	12.91	6.11	4.89	4.89	6.11	4.89	4.89	6.11	4.89	4.89	6.11	4.89	4.89
VOC	3.20	1.51	1.21	1.21	1.51	1.21	1.21	1.51	1.21	1.21	1.51	1.21	1.21
NO_x	13.50	6.39	5.11	5.11	6.39	5.11	5.11	6.39	5.11	5.11	6.39	5.11	5.11
PM	2.33	1.10	0.88	0.88	1.10	0.88	0.88	1.10	0.88	0.88	1.10	0.88	0.88
SO_2	0.87	0.41	0.33	0.33	0.41	0.33	0.33	0.41	0.33	0.33	0.41	0.33	0.33

Emission Factors from Gover et al. (1996).

used is transferred as useful work.

Table 7.10 - Heat Losses from Company D (GJ).

Period	Energy In	Heat Loss	Period	Energy In	Heat Loss
7	43,930	6,887	1	40,297	6,306
8	41,428	6,459	2	39,595	6,224
9	45,035	7,038	3	39,972	6,272
10	49,786	7,772	4	44,665	7,013
11	39,452	6,188	5	37,892	5,912
12	29,898	4,704	6	37,411	5,826

7.2.7.3 Land Area.

The area of land owned by the site covers 134,973m^2. It is assumed that all of this land is covered by the site's operations.

7.2.7.4 Electricity Use.

Electricity is the second source of energy for the site. Although the use of electricity has no direct environmental burden, it is going to be used to estimate the contribution of an indirect process on the company. The usage figures used to calculate this contribution, from the emissions of a variety of electricity generators, are given in Table 7.11.

Table 7.11 - Electricity Use at Company D (KWh).

Period	7	8	9	10	11	12
Usage	2,798,700	2,268,000	2,351,900	2,894,900	2,339,000	1,555,300
Period	1	2	3	4	5	6
Usage	2,317,900	2,232,800	2,236,200	2,759,400	2,205,100	2,185,400

7.3 The Integrated Environmental Index.

The IEI is only calculated for those substances released via point-sources. Internal transport and distribution emissions will, therefore, not be included the assessment. All releases are firstly tested for significance, as discussed in section 2.3.3. The required release rates have been calculated using the site running hours to give a monthly average. The release rate and significance limits for

Table 7.12 - Air Release Rates & Limits for Company D (g/s).

Period Param.	7	8	9	10	11	12	1	2	3	4	5	6	Air Limit	Land Limit
R. Hrs	840	672	672	840	672	672	840	672	672	840	672	672		
SO_2	**13.006**	**12.265**	**13.333**	**11.791**	**8.736**	**8.851**	**9.544**	**11.722**	**11.834**	**10.578**	**11.218**	**11.076**	4.500	N/A
NO_x	4.260	4.018	4.368	3.863	3.826	2.900	3.127	3.840	3.877	3.466	3.675	3.628	5.150	N/A
Al_2O_3	0.294	0.287	0.296	0.309	0.282	0.257	0.284	0.282	0.283	0.295	0.278	0.277	0.470	N/A
Fe_2O_3	0.109	0.107	0.111	0.115	0.105	0.096	0.106	0.105	0.106	0.110	0.104	0.103	0.193	N/A
CaO	0.028	0.027	0.028	0.030	0.027	0.025	0.027	0.027	0.027	0.028	0.027	0.026	0.250	N/A
Ni	**0.00540**	**0.00528**	**0.00545**	**0.00568**	**0.00519**	0.00473	**0.00523**	**0.00519**	**0.00521**	**0.00543**	**0.00511**	**0.00509**	0.003	0.08
Mn	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.014	N/A
Be	**0.005**	**0.00013**	**0.00013**	**0.00014**	**0.00013**	**0.00012**	**0.00013**	**0.00013**	**0.00013**	**0.00013**	**0.00013**	**0.00013**	0.00005	N/A
Zn	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	N/A	0.8
Cu	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.014	0.145
Co	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.075
Ba	**0.003**	**0.00311**	**0.00321**	**0.00334**	**0.00305**	**0.00278**	**0.00308**	**0.00306**	**0.00307**	**0.00320**	**0.00301**	**0.00299**	0.00250	0.07500
Cr	0.003	0.007	0.007	0.008	0.007	0.006	0.007	0.007	0.007	0.007	0.007	0.007	0.065	N/A
Parts	**3.448**	**3.371**	**3.482**	**3.627**	**3.311**	3.019	**3.337**	**3.315**	**3.327**	**3.470**	**3.263**	**3.249**	**3.200**	N/A

Bold = Significant release for air quality.
Underlined = Significant release for deposition to land.
Calculated for stack height of 60m from HMIP (1995b).

Table 7.13 - Water Release Rates & Limits for Company D (ug/s).

Param	Hg	Ni	Zn	Pb	As	Fe	Sn	Cr	Cu	Cd	NH^{4+}	Suspended Solids (S.S.)	BOD
Period													
7	0.008	7.815	**226.947**	**101.539**	37.671	23.708	**207.617**	**47.219**	**308.541**	2.984	15.223	**571,015.284**	**448,434.537**
8	0.084	7.962	**215.068**	**93.137**	35.024	29.867	**187.347**	**51.677**	**331.338**	3.602	**19.029**	**551,848.387**	**365,647.650**
9	0.068	7.879	**220.870**	**97.291**	36.328	25.296	**197.400**	**49.387**	**291.739**	3.288	**19.029**	**552,751.171**	**366,734.284**
10	0.054	6.959	**201.900**	**90.293**	33.504	30.225	**184.584**	**42.095**	**283.388**	2.666	15.223	**420,688.889**	**267,494.497**
11	0.060	7.093	**203.167**	**90.361**	33.610	34.996	**184.224**	**43.479**	**287.857**	2.807	**19.029**	**535,027.778**	**353,549.372**
12	0.047	5.508	**155.174**	**68.504**	25.558	21.343	**139.147**	**34.357**	**200.709**	2.272	**19.029**	**621,423.611**	**539,889.881**
1	0.056	5.348	**147.616**	**64.621**	24.191	21.683	**130.703**	**33.912**	**193.450**	2.299	15.223	**440,000.000**	**367,724.868**
2	0.085	8.059	**225.296**	**99.156**	37.039	34.980	**201.099**	**50.567**	**303.057**	3.376	**19.029**	**619,972.222**	**538,632.011**
3	0.060	7.674	**223.087**	**99.908**	37.054	6.277	**204.377**	**46.201**	**315.505**	2.911	**19.029**	**716,527.778**	**693,966.270**
4	0.054	6.847	**197.809**	**88.339**	32.799	17.695	**180.463**	**41.523**	**245.304**	2.643	15.223	**426,800.000**	**324,714.868**
5	0.003	8.240	**228.072**	**99.988**	37.412	25.388	**202.388**	**52.065**	**315.663**	3.512	**19.029**	**602,861.111**	**463,516.270**
6	0.003	0.008	0.000	0.000	0.008	17.383	0.000	0.000	**62.950**	0.000	**19.029**	**824,618.056**	**372,400.876**
Limit	3.820	191.000	30.560	15.280	191.000	3,820.000	N/A	19.100	3.820	19.100	15.280	95.500	11.460

Bold = Significant release for water quality.
Limits calculated for average river discharge of $1.93m^3/s$ from HMIP (1995b).
Average river discharge from SEPA (1996b)

emissions to air are given in Table 7.12 and in Table 7.13 for water. Significant releases are shown in **bold** or underlined. For those substances released at a significant rate during a given month, a more detailed assessment must be carried out, using the modelling techniques described in section 3.3.

7.3.1 Emissions to Air.

For releases to air the ISCLT model combines meteorological and topographic data with technical data to predict the dispersion of significant releases from Table 7.12. The technical data for the site is given in Table 7.14.

Table 7.14 - Technical Data for Air Emissions from Company D.

Parameter	Value
Stack Height (m)	60
Exit Diameter (m)	3.35
Exit Velocity (m/s)	4.10
Exit Temperature (°C)	150
X Co-ordinate (m)	0
Y Co-ordinate (m)	0

Meteorological data from Turnhouse was used (Meteorological Office 1995c), with topographic data derived from local Ordnance Survey (1976 & 1988) maps (see Table 7.15).

Table 7.15 - Polar Grid Elevation Heights for Company D (m).

Distance (m)	50	250	500	750	1,000	2,000	3,000	4,000	5,000
Direction (°)									
45	65	85	75	55	55	75	115	85	60
90	65	60	55	45	45	40	40	70	55
135	70	70	70	75	60	85	75	40	50
180	75	90	85	75	90	110	75	35	100
225	80	95	95	105	120	150	165	130	115
270	75	85	100	120	125	170	250	340	250
315	70	65	110	145	145	200	160	200	215
360	65	95	85	85	85	135	100	125	90
Base Height	70								

Polar grid co-ordinates centred on (0 , 0).
From Ordnance Survey (1976 & 1988)

Table 7.16 - Predicted Concentrations in Air for Company D (ug/m^3).

	Period	7	8	9	10	11	12	1	2	3	4	5	6
Param.	EQS / EAL (ug/m^3)												
SO_2	80	1.359834	1.602969	1.742510	1.541091	1.141775	1 156848	1.247379	1.532037	1.546623	1.382566	1.466183	1.447545
Ni	0.2	0.000760	0.000745	0.000767	0.000797	0.000732	-	0.000738	0.000733	0.000736	0.000765	0.000723	0.000720
Be	0.004	0.000072	0.000072	0.000072	0.000073	0.000072	0.000070	0.000072	0.000072	0.000072	0.000072	0.000071	0.000071
Ba	5	0.000470	0.000461	0.000474	0.000492	0.000454	0.000418	0.000457	0.000454	0.000456	0.000473	0.000448	0.000446
Parts.	80	0.450669	0.440674	0.455082	0.474059	0.432782	-	0.436157	0.433353	0.434859	0.453602	0.426552	0.424631

Table 7.17 - Environmental Quotients ($EQ_{(S)}$) and $EQ_{(Air)}$ for Company D.

Period	7	8	9	10	11	12	1	2	3	4	5	6
Parameter												
SO_2	0.01700	0.02004	0.02178	0.01926	0.01427	0.01446	0.01559	0.01915	0.01933	0.01728	0.01833	0.01809
Ni	0.00380	0.00372	0.00384	0.00399	0.00366	0.00000	0.00369	0.00367	0.00368	0.00383	0.00361	0.00360
Be	0.01806	0.01797	0.01810	0.01829	0.01789	0.01752	0.01792	0.01789	0.01791	0.01809	0.01783	0.01781
Ba	0.00009	0.00009	0.00009	0.00010	0.00009	0.00008	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009
Parts.	0.00563	0.00551	0.00569	0.00593	0.00541	0.00000	0.00545	0.00542	0.00544	0.00567	0.00533	0.00531
$EQ_{(Air)}$	0.04459	0.04733	0.04951	0.04756	0.04132	0.03206	0.04275	0.04622	0.04645	0.04496	0.04519	0.04490

Using the above data the model was run for each substance in each month to predict the location with the maximum average annual concentration. Table 7.16 shows the results for significant releases from Company D. The table also shows the EQSs or EALs for the substances concerned. These are used to calculate the EQ for air (see Table 7.17), as described in section 2.3.3.

7.3.2 Emissions to Water.

For emissions to riverine surface waters a mass balance model was used to estimate the dispersion of significant releases from Table 7.13. The Warn-Brew model looks at the distribution of river discharge and combines this with data on the distribution of the outfall discharge and pollutant concentrations as described in section 3.3.2.

The flow distribution curve for the river to which Company D discharges is shown in Table 7.18. The model also requires the mean and standard deviation of the effluent discharge and the concentration of the pollutants rather than the release rates given in Table 7.13. The mean concentration was estimated using the total effluent discharge figures (see Table 7.19) and emission data in Table 7.5, with the

Table 7.18 - Flow Distribution Curve for River at Company D.

Percentile (%)	River Flow (Ml/day)	Percentile (%)	River Flow (Ml/day)
5	734.26	55	74.72
10	500.34	60	64.79
15	359.97	65	58.31
20	270.64	70	52.65
25	211.54	75	49.66
30	174.56	80	45.42
35	145.07	85	42.50
40	121.53	90	39.77
45	101.61	95	35.66
50	86.53		

From SEPA (1996b).

Table 7.19 - Effluent Concentration Data (Monthly Average & Range) for Company D (ug/l).

Parameter Period	Zn	Pb	Cr	Sn	Cu	NH^{4+}	S.S.	BOD	Effluent Out (l/day)
Average									
7	11.39	5.10	2.37	10.42	15.49	0.76	28,658.25	22,506.14	2,152
8	8.59	3.72	2.06	7.48	13.23	0.76	22,029.80	14,596.66	2,164
9	7.04	3.10	1.58	6.30	9.31	0.61	17,629.27	11,696.50	2,709
10	10.13	4.53	2.11	9.26	14.22	0.76	21,108.91	13,422.07	2,152
11	8.16	3.63	1.75	7.40	11.57	0.77	21,498.71	14,206.47	2,150
12	4.95	2.19	1.10	4.44	6.41	0.61	19,831.15	17,229.21	2,707
1	7.40	3.24	1.70	6.55	9.69	0.76	22,043.39	18,422.51	2,156
2	9.04	3.98	2.03	8.07	12.16	0.76	24,869.09	21,606.27	2,154
3	7.14	3.20	1.48	6.55	10.10	0.61	22,946.51	22,223.99	2,698
4	9.98	4.46	2.10	9.11	12.38	0.77	21,540.26	16,388.10	2,140
5	9.13	4.00	2.08	8.10	12.64	0.76	24,133.60	18,555.38	2,158
6	-	-	-	-	2.02	0.61	26,425.90	11,934.04	2,696
CV	38.38%	38.64%	37.64%	38.79%	34.10%	10.74%	13.02%	22.83%	11.58%
Range									
7	4.37	1.97	0.89	4.04	5.28	0.08	3,731.86	5,138.41	249
8	3.29	1.44	0.78	2.90	4.51	0.08	2,868.71	3,332.59	251
9	2.70	1.20	0.59	2.44	3.17	0.07	2,295.67	2,670.45	314
10	3.89	1.75	0.80	3.59	4.85	0.08	2,748.79	3,064.41	249
11	3.13	1.40	0.66	2.87	3.94	0.08	2,799.55	3,243.50	249
12	1.90	0.84	0.41	1.72	2.18	0.07	2,582.40	3,933.63	313
1	2.84	1.25	0.64	2.54	3.30	0.08	2,870.48	4,206.07	250
2	3.47	1.54	0.76	3.13	4.14	0.08	3,238.44	4,932.96	249
3	2.74	1.24	0.56	2.54	3.44	0.07	2,988.08	5,074.00	312
4	3.83	1.72	0.79	3.53	4.22	0.08	2,804.96	3,741.59	248
5	3.50	1.55	0.78	3.14	4.31	0.08	3,142.66	4,236.41	250
6	0.00	0.00	0.00	0.00	0.69	0.07	3,441.17	2,724.68	312

Table 7.20 - Predicted Environmental Concentrations for Releases to Water from Company D (ug/l).

Parameter	Period EQS / EAL (ug/l)	7	8	9	10	11	12	1	2	3	4	5	6
NH^{4+}	19	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BOD	3,000	1,545.43	1,004.35	876.73	921.66	975.21	1,291.01	1,265.90	1,484.12	1,663.05	1,123.10	1,275.44	892.78
Cr	5	0.16	0.14	0.12	0.15	0.12	0.08	0.12	0.14	0.11	0.15	0.14	-
Cu	1	1.07	0.92	0.70	0.98	0.80	0.48	0.67	0.84	0.76	0.86	0.88	0.15
Pb	4	0.35	0.26	0.23	0.31	0.25	0.17	0.23	0.28	0.24	0.31	0.28	-
S.S.	25,000	1,955.09	1,505.94	1,268.73	1,440.07	1,466.19	1,476.56	1,504.86	1,697.13	1,706.23	1,466.58	1,648.08	1964.38
Sn	25	0.72	0.52	0.48	0.64	0.51	0.34	0.46	0.56	0.50	0.63	0.56	-
Zn	8	0.79	0.60	0.53	0.70	0.57	0.37	0.51	0.63	0.54	0.69	0.63	-

Table 7.21 - Environmental Quotients (EQ_s) and EQ_{Water} for Company D.

Period Parameter	7	8	9	10	11	12	1	2	3	4	5	6
NH^{4+}	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632	0.002632
BOD	0.515143	0.334783	0.292243	0.307220	0.325070	0.430337	0.421967	0.494707	0.554350	0.374367	0.425147	0.297593
Cr	0.032000	0.028000	0.024000	0.030000	0.024000	0.016000	0.024000	0.028000	0.022000	0.030000	0.028000	0.000000
Cu	1.070000	0.920000	0.700000	0.980000	0.800000	0.480000	0.670000	0.840000	0.760000	0.860000	0.880000	0.150000
Pb	0.087500	0.065000	0.057500	0.077500	0.062500	0.042500	0.057500	0.070000	0.060000	0.077500	0.070000	0.000000
S.S.	0.078204	0.060238	0.050749	0.057603	0.058648	0.059062	0.060194	0.067885	0.068249	0.058663	0.065923	0.078575
Sn	0.028800	0.020800	0.019200	0.025600	0.020400	0.013600	0.018400	0.022400	0.020000	0.025200	0.022400	0.000000
Zn	0.098750	0.075000	0.066250	0.087500	0.071250	0.046250	0.063750	0.078750	0.067500	0.086250	0.078750	0.000000
$EQ_{(Water)}$	1.913029	1.506453	1.212574	1.568054	1.364499	1.090381	1.318443	1.604373	1.554731	1.514611	1.572851	0.528800

standard deviations derived for each pollutant using the coefficient of variation for that pollutant over the year. The data used for the model is given in Table 7.19.

The predicted concentrations, which represent the location with the maximum annual average concentration, resulting from the significant releases to water are given in Table 7.20. Table 7.20 also shows the EQSs or EAL for each substance, which are used to calculate the EQ for water in Table 7.21.

7.3.3 Emissions to Land.

Company D has no significant direct or indirect releases to land (see Table 7.12) The EQ for land is, therefore, zero.

Table 7.22 - EQ$_{Air)}$, EQ$_{Water)}$, EQ$_{(Land)}$ and the IEI for Company D.

Period	EQ $_{Air}$	EQ$_{(Water)}$	EQ$_{(Land)}$	IEI
7	0.044589	1.913029	-	1.957618
8	0.047327	1.506453	-	1.553780
9	0.049506	1.212574	-	1.262080
10	0.047561	1.568054	-	1.615615
11	0.041324	1.364499	-	1.405823
12	0.032064	1.090381	-	1.122445
1	0.042746	1.318443	-	1.361188
2	0.046219	1.604373	-	1.650593
3	0.046447	1.554731	-	1.601178
4	0.044962	1.514611	-	1.559574
5	0.045191	1.572851	-	1.618042
6	0.044900	0.528800	-	0.573700

7.3.4 The Integrated Environmental Index.

The EQs for air, water and land, and the resulting IEI for Company D are shown in Table 7.22.

7.4 The Total Environmental Potency Index.

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 7.1, Table 7.3, and Table 7.5 to Table 7.10.

Each of the substances covered by the TEPI is allocated a series of potency factors which describe its contribution to different environmental potency categories, as discussed in section 3.4. The category totals and TEPI from these emissions are given in Table 7.23. In order to assess the effect of electricity use on the site's total potency in section 11.3.3, the usage data in Table 7.11 has been used to calculate the TEPI for electricity, based on the average UK generation mix (see Table 7.24). This data has not been included in the site totals being used for the comparative study.

Table 7.23 - Category Totals and TEPI for Company D (x1,000).

Period	7	8	9	10	11	12	1	2	3	4	5	6
Category												
GWP	4,101	3,872	4,216	4,680	3,726	2,794	3,816	3,823	3,851	4,301	3,630	3,545
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	11,059	8,652	8,935	11,633	8,496	7,746	10,702	8,508	8,538	11,131	8,375	8,337
AETP	2	1	2	2	1	1	2	1	1	2	1	1
TETP	20,425	15,979	16,501	21,486	15,692	14,308	19,768	15,714	15,768	20,559	15,465	15,396
POCP	2	2	2	2	1	1	2	2	2	2	2	2
AP	40	38	41	45	29	27	37	37	37	42	35	34
NP	2	2	2	2	2	1	2	2	2	2	2	2
WH	7	6	7	7	6	4	6	6	6	7	6	6
LA	135	135	135	135	135	135	135	135	135	135	135	135
TEPI	35,771	28,686	29,840	37,993	28,088	25,018	34,469	28,228	28,340	36,180	27,650	27,457

Table 7.24 - Category Totals and TEPI for Electricity Used at Company D (UK Average).

Period	7	8	9	10	11	12	1	2	3	4	5	6
Cat.												
GWP	1,822,104	1,476,590	1,531,213	1,884,735	1,522,815	1,009,329	1,509,077	1,453,673	1,455,886	1,796,518	1,435,639	1,422,813
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	2,527	2,047	2,123	2,613	2,112	1,400	2,093	2,016	2,019	2,491	1,991	1,973
AETP	0	0	0	0	0	0	0	0	0	0	0	0
TETP	0	0	0	0	0	0	0	0	0	0	0	0
POCP	579	469	487	599	484	321	479	462	463	571	456	452
AP	10,864	8,804	9,130	11,238	9,080	6,018	8,998	8,667	8,681	10,712	8,560	8,483
NP	692	561	582	716	579	384	573	552	553	683	546	541
WH	20	16	17	21	17	11	17	16	16	20	16	16
LA	1	1	1	1	1	1	1	1	1	1	1	1
TEPI	1,836,787	1,488,489	1,543,552	1,899,923	1,535,086	1,017,462	1,521,238	1,465,387	1,467,618	1,810,995	1,447,208	1,434,278

CHAPTER EIGHT

Company E

Micro-Electronics

8.1 The Company.

Company E is a micro-electronics manufacturer taking part as a black box site. The company is part of a multi-national group, producing micro-processor chips and communications and control products. Environmental management is the responsibility of the environmental manager, who reports to the EHS director. The company does not produce a publicly available annual environmental report, but does collect and provide an internal set of environmental performance metrics. The site is subject to IPC for releases to air and water and is not accredited to an environmental management standard. The site employs 2,500 people. A lack of company resources mean that the site was only able to provide quarterly data for the period of the study.

8.2 The Micro-Electronics Process & Emissions.

Company E manufactures micro-chips from a silicon disc base, onto which layers of metals and insulators are applied and removed using a wide variety of processes. The energy and material flows associated with these processes are shown in Figure 8.1. The emissions from these processes have been derived primarily from company data, or estimated using simple mass balance techniques, as it has not been possible to go into the details of the many different processes present on site. Emissions from the site occur to both air and water, with no direct releases to land.

8.2.1 Emissions to Air.

Air emissions from the site are derived from a number of sources. For each of these sources the emissions have been calculated in different ways, depending on data availability and accessibility. They have been broken down into gas, solvent, and utility emissions.

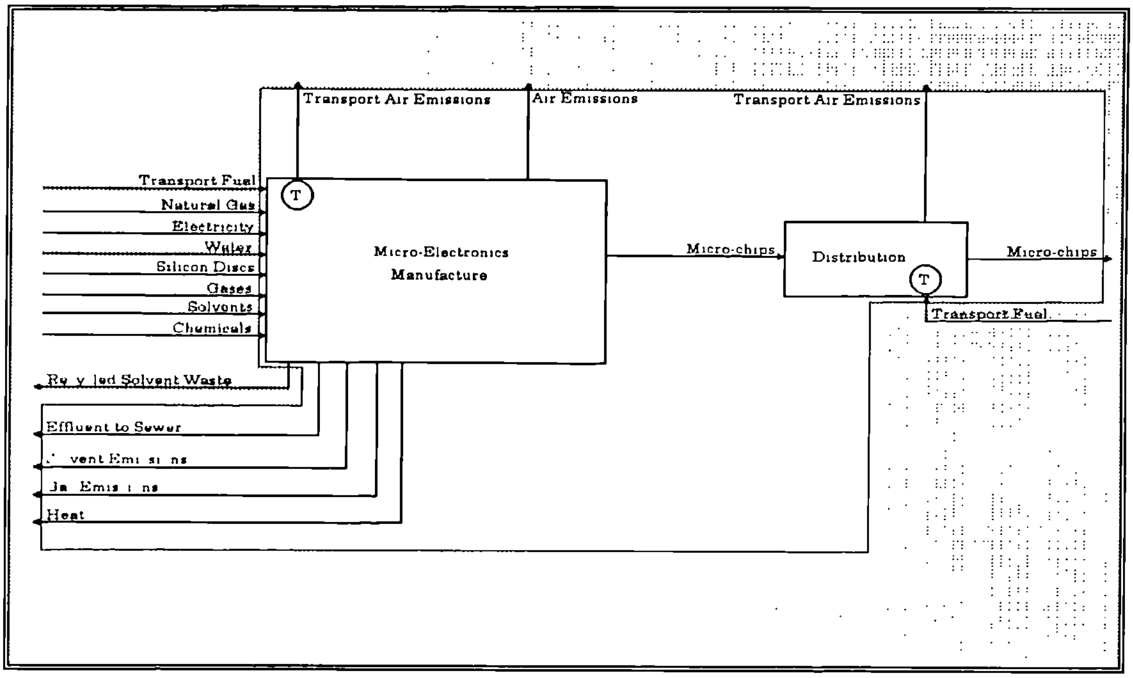


Figure 8.1 - The Boundaries and Material & Energy Flows for Company E.

8.2.1.1 Gas Emissions.

Emissions of gas from the site have been estimated from usage figures, assuming that all the gas used is emitted directly to air, with no reactions taking place with

Table 8.1 - Gas Emissions to Air from Company E (Kg).

Period Gas	Q1	Q2	Q3	Q4
Hydrogen chloride	54.40	81.60	190.40	81.60
Ammonia	182.90	219.10	182.90	162.90
Dichlorosilane	0.94	81.60	86.20	0.00
Dinitrogen oxide	2,088.60	2,301.00	2,301.00	2,442.60
Carbon tetraflouride	330.51	428.89	650.02	308.08
Triflouromethane	270.00	180.00	140.00	140.00
Hexaflouroethane	1,264.80	1,509.60	2,162.40	1,468.80
Sulphur hexaflouride	240.00	400.00	440.00	109.20
Silane	258.25	218.25	246.60	254.90
Phosphine	217.86	24.00	18.57	20.03
Boron triflouride	4.60	4.80	4.96	5.39
Arsine	1.19	1.57	1.71	2.05
Chlorine	350.00	200.00	400.00	250.00
Diborane	3.80	3.75	4.13	120.00
Nitrogen triflouride	45.36	22.68	136.08	45.36
Boron triflouride	0.00	0.00	22.00	0.00

other constituents in the process or stacks. This was done as only small amounts of the gases used actually remain on the silicon disc to which they are applied. The estimated emissions of gases are given in Table 8.1.

8.2.1.2 Solvent Emissions.

Solvent emissions from the site have been estimated by taking the solvent recovery figures from the usage figures for the site.

Table 8.2 - Solvent Emissions to Air from Company E (Kg).

Period	Q1	Q2	Q3	Q4
Solvent				
Methanol	6,034	3,349	3,817	268
IPA	5,101	10,418	11,945	2,773
n-Methyl-pyrollidone	407	1,892	2,825	1,279
Butyl acetate	2,334	5,651	6,148	4,239
Acetone	2,901	2,119	2,482	1,878
HMDS	367	195	202	525
PGMEA	4,968	17,407	9,685	8,306
Xylene	2,013	2,739	2,383	1,784
White spirit	2,178	3,636	3,757	429
Ethyl methoxy proprionate	157	226	302	180
Ethyl lactate	249	343	478	271
Petrol	2,071	5,116	4,449	2,550
Cellosolve acetate	80	0	0	0
Ethylene glycol	18	0	0	0
Ethyl acetate	6	0	0	0

This assumes that all the remaining solvent is released to air via the stacks, and that each solvent is removed to the same degree by the scrubbers. The resulting estimates for solvent emissions are shown in Table 8.2.

8.2.1.3 Utility Emissions.

Emissions to air from the steam utility have been estimated from usage data and emission factors for the natural gas burnt at the site, as discussed in section 6.2.4. The resulting emission totals are given in Table 8.3.

Table 8.3 - Fuel Combustion Emissions to Air from Company E (Kg).

Period Parameter	Q1	Q2	Q3	Q4
CO_2	2,707,737	1,960,299	1,325,272	1,593,483
SO_2	25	18	12	15
NOx	50,067	36,247	24,505	29,464

8.2.2 Emissions to Water.

Emissions to water originate from the liquid chemicals used in the process, as well as the scrubbing of gases from the stacks. Data on the quantity of chemicals released has been estimated from two different sources. Firstly, company data on the effluent concentration of metals, halides, sulphate, suspended solids, COD and BOD was combined with effluent flow data. Secondly, chemical usage data was used to estimate emissions for ammonia, nitrate and phosphate. Each parameter has been multiplied by a Water Treatment Removal Factor (WTRF), to take account of the processes taking place at the public sewage works through which the emissions are discharged to riverine surface water. A WTRF of 70% was used for all substances, except fluoride and chloride for which a factor of 0% was used, and nitrate and phosphate for which a factor of 0.1% was used. The final emission totals, after removal, are shown in Table 8.4.

Table 8.4 - Emissions to Water from Company E (Kg).

Period Parameter	Q1	Q2	Q3	Q4
Ammonia	7.77	4.78	3.40	1.44
Nitrate	4.43	4.28	1.01	5.10
Phosphate	20.42	8.33	10.10	10.67
Tin	7.34	16.96	6.11	9.95
Cadmium	0.75	1.25	0.78	0.96
Iron	1.53	2.09	1.35	1.72
Copper	1.46	2.00	1.20	2.08
Zinc	0.82	1.18	0.87	1.07
Lead	1.43	1.63	1.20	1.53
Nickel	1.12	0.80	0.58	0.85
Arsenic	0.84	0.80	0.58	0.85
Suspended solids	260	500	275	376
COD	3,977	4,530	2,533	4,324
BOD	491	411	607	648

8.2.3 Distribution.

The products from Company E are distributed throughout the UK and Europe, using road transport. However, no form of distribution or client data was available from the company.

8.2.4 Site Parameters.

A number of parameters used by TEPI are relevant to all of the process and are best covered as a whole for the site.

8.2.4.1 Internal Transport.

There are no direct emissions from internal transport at Company E.

8.2.4.2 Heat Losses.

Heat losses from the boilers of the site were estimated using a thermal efficiency of 85% (see Table 8.5).

Table 8.5 - Heat Losses from Company E (GJ).

Period	Q1	Q2	Q3	Q4
Energy In	49,428	35,784	24,192	29,088
Heat Loss	7,414	5,368	3,629	4,363

It is assumed that all the energy in the steam generated performs useful work on the site.

8.2.4.3 Land Area.

The area of land owned by the site covers 114,312m^2. It is assumed that all of this land is covered by the site's operations.

8.2.4.4 Electricity Use.

Electricity is the primary source of energy for this site. Although the use of electricity has no direct environmental burden, it will be used to estimate the contribution of an indirect process on the company. The usage figures used to calculate this contribution, from the emissions of a variety of electricity generators, are given in Table 8.6.

Table 8.6 - Electricity Use at Company E (KWh).

Period	Q1	Q2	Q3	Q4
Electricity Usage	28,740,000	38,050,000	33,110,000	39,200,000

8.3 The Integrated Environmental Index.

The IEI is only calculated for those substances released via point-sources. All releases are firstly tested for significance, as discussed in section 2.3.3.

Table 8.7 - Air Release Rates & Limits for Company E (g/s).

Period Parameter	Q1	Q2	Q3	Q4	Air Limit	Land Limit	Stack Height
HCL	**0.007**	**0.010**	**0.024**	**0.010**	0.003	N/A	14m
NH_3	0.023	0.028	0.023	0.021	0.034	N/A	14m
SiH_4	**0.033**	**0.028**	**0.031**	**0.032**	0.003	N/A	14m
AsH_4	0.00015	0.00020	0.00022	0.00026	0.00056	N/A	12m
Cl_2	**0.04452**	**0.02544**	**0.05088**	**0.03180**	0.00052	N/A	14m
B_2H_6	**0.00048**	0.00047	**0.00052**	**0.01526**	0.00047	N/A	14m
NF_3	0.0058	0.0029	0.0173	0.0058	0.104	N/A	21m
Methanol	0.77	0.43	0.49	0.03	5.8	N/A	30m
IPA	0.6	1.3	1.5	0.4	4.9	N/A	12.5m
MPD	0.052	0.241	0.360	0.163	4.357	N/A	22.3
Butl acete	0.30	0.72	0.78	0.54	3.54	N/A	16m
Acetone	0.37	0.27	0.32	0.24	8.88	N/A	16m
PGMEA	0.63	2.21	1.23	1.06	1.48	N/A	16m
Xylene	0.256	0.348	0.303	0.227	2.16	0.268	16m
Wht sprt	0.28	0.46	0.48	0.05	2.74	N/A	30m
Cellosolve	0.01	0.00	0.00	0.00	12.8	N/A	16m
Ethle gly	0.002	0.000	0.000	0.000	0.272	N/A	16m
Ethl. ace	0.0008	0.0000	0.0000	0.0000	7	N/A	16m
SO_2	0.003	0.002	0.002	0.002	0.5	N/A	24m
NO_x	0.301	0.218	0.147	0.177	0.54	N/A	24m
Rn. Hrs.	2184	2184	2184	2184			

Bold = Significant release for air quality.
Underlined = Significant release for deposition to land.
Limits calculated for stack heights given from HMIP (1995b).

The required release rates have been calculated using the running hours to give a monthly average. The release rates and significance limits for emissions to air are given in Table 8.7 and in Table 8.8 for water. Significant releases are shown in **bold** or underlined. For those substances released at a significant rate during a given quarter, a more detailed assessment must be carried out, using the modelling techniques described in section 3.3.

Table 8.8 - Water Releases Rates & Limits for Company E (g/s).

Period	Q1	Q2	Q3	Q4	Limit
Parameter					
NH^{4+}	**987.81**	**607.37**	**432.48**	**182.77**	6.33
Sn	**933.168**	**2,156.725**	**776.721**	**1,265.777**	N/A
Cd	**95.41**	**159.43**	**99.08**	**122.46**	7.91
Fe	195	265	172	219	1582
Cu	**186.24**	**254.08**	**152.85**	**264.32**	1.58
Zn	**103.68**	**150.43**	**111.18**	**135.45**	12.66
Pb	**181.71**	**206.72**	**152.51**	**195.04**	6.33
Ni	**142.0**	**102.0**	73.5	**107.6**	79.1
As	**106.7**	**102.0**	73.5	**107.6**	79.1
S.S.	**33,007.86**	**63,574.27**	**34,950.34**	**47,873.28**	39.55
BOD	**62,414.74**	**52,323.73**	**77,228.21**	**82,370.08**	4.75

Bold = Significant release for water quality.
Limits calculated for average discharge of 0.791m^3/s from HMIP (1995b).
Average discharge from SEPA (1996a).

8.3.1 Emissions to Air.

For releases to air the ISCLT model combines meteorological and topographic data with technical data to predict the dispersion of significant releases from Table 8.7. The technical data for the site is given in Table 8.9. Meteorological data from Prestwick was used (Meteorological Office 1995b), with topographical data derived from a local Ordnance Survey (1988) map (see Table 8.10).

The emission rates used for the model are different to those in Table 8.7, as each substance is released from different stacks. The significance test examined the total release rate for the site, whereas the model requires stack specific data.

Table 8.9 - Technical Data for Air Emissions from Company E.

Stack Number	1	2	3	4	5	6	7	8	9	10
Stack Height (m)	24	12	14	14	14	14	14	16	17	17
Exit Diameter (m)	0.30	0.50	0.40	0.25	0.41	0.25	0.25	0.18	0.30	0.30
Exit Velocity (m/s)	15.00	22.00	5.50	18.00	15.00	6.50	4.30	15.00	15.00	13.60
Exit Temperature (°C)	475.0	292.5	294.5	296.0	294.4	294.6	294.4	291.0	290.6	290.0
X Co-ordinate (m)	171.50	70.00	71.75	73.50	75.25	96.25	98.00	77.00	82.25	84.00
Y Co-ordinate (m)	171.50	91.44	86.63	81.81	77.00	19.25	14.44	72.19	57.75	52.94
Substances Emitted	NO_x SO_2 CO_2	AsH_3 BF_3 C_2F_6 CF_4 CHF_3 PH_3	CF_4 NH_3 SiH_4	HCl SiH_4	B_2H_6 C_2F_6 N_2O PH_3	PH_3 SiH_4	PH_3 SiH_4	Acetone Butyl Acetate Cellosolve Ethyl Acetate Ethylene Glycol Ethyl Lactate EMP IPA Petrol PGMEA Xylene	Acetone Butyl Acetate Cellosolve Ethyl Acetate Ethylene Glycol Ethyl Lactate EMP HMDS IPA Petrol PGMEA Xylene	Acetone Butyl Acetate Cellosolve Ethyl Acetate Ethylene Glycol Ethyl Lactate EMP HMDS IPA Petrol PGMEA Xylene

Table 8.9 contd. - Technical Data for Air Emissions from Company E.

Stack Number	11	12	13	14	15	16	17	18	19	20
Stack Height (m)	17	16	16	16	16	17	12.5	17	30	30
Exit Diameter (m)	0.30	0.25	0.25	0.25	0.25	0.45	0.25	0.20	0.80	0.58
Exit Velocity (m/s)	14.40	8.00	8.00	10.00	5.80	3.70	1.70	47.00	14.00	8.75
Exit Temperature (°C)	290.7	296.4	296.4	294.0	295.0	292.0	291.0	291.0	293.0	293.0
X Co-ordinate (m)	85.75	78.75	80.50	92.75	94.50	87.50	103.25	89.25	34.04	36.05
Y Co-ordinate (m)	48.13	67.38	62.56	28.88	24.06	43.31	0.00	38.50	164.50	159.25
Substances Emitted	Acetone C_2F_6 Cellosolve CF_4 CHF_3 Cl_2 Ethyl Lactate	AsH_3 BF_3 PH_3	DCS NH_3	C_2F_6 CF_4 CHF_3	CF_4 NH_3 SiH_4	DCS NH_3	C_2F_6 CF_4 CHF_3 IPA	B_2H_6 PH_3 SiH_4	Acetone Cellosolve Ethyl Lactate HMDS IPA Methyl Pyrollidone PGMEA Petrol	Acetone Butyl Acetate Cellosolve Ethyl Lactate IPA Methanol Naptha Petrol

Table 8.9 contd. - Technical Data for Air Emissions from Company E.

Stack Number	21	22	23	24	25	26	27	28	29	30
Stack Height (m)	30	30	30	30	30	22.3	28.3	28.3	28.3	14
Exit Diameter (m)	0.30	0.55	0.55	0.65	0.30	1.00	0.50	0.30	0.30	0.75
Exit Velocity (m/s)	0.80	11.20	14.20	10.50	9.20	15.00	3.36	8.14	8.71	19.30
Exit Temperature (°C)	293.4	295.0	295.0	295.0	295.0	291.0	296.4	296.0	296.0	291.0
X Co-ordinate (m)	63.00	38.06	40.08	38.50	50.75	28.00	46.11	32.03	30.02	99.75
Y Co-ordinate (m)	210.00	154.00	148.75	201.25	206.50	180.25	133.00	169.75	175.00	14.44
Substances Emitted	IPA	B_2H_6 DCS N_2O NH_3 PH_3 SiH_4	DCS HCl NH_3 SiH_4	AsH_3 B_2H_6 PH_3	AsH_3 B_2H_6 PH_3	DCS HCL NH_3 SiH_4	B_2H_6 DCS NH_3 PH_3 SiH_4	B_2H_6 DCS NH_3 PH_3 SiH_4	B_2H_6 DCS NH_3 PH_3 SiH_4	BCl_3 Cl_2 HCL NH_3

Table 8.9 contd. - Technical Data for Air Emissions from Company E.

Stack Number	31	32	33	34	35	36	37	38	39	40
Stack Height (m)	14	30	30	21	17	22.3	22.3	22.3	24	24
Exit Diameter (m)	0.75	0.90	0.90	0.93	0.30	1.40	0.80	0.50	0.80	0.70
Exit Velocity (m/s)	28.60	17.00	23.40	5.70	14.00	14.30	14.30	14.30	14.30	14.30
Exit Temperature (°C)	291.0	292.0	291.5	291.0	291.0	290.0	290.0	290.0	291.0	291.0
X Co-ordinate (m)	101.50	42.09	44.10	48.13	91.00	110.25	113.75	117.25	120.75	126.00
Y Co-ordinate (m)	9.63	143.50	138.25	127.75	33.69	204.75	192.50	18025	169.75	157.50
Substances Emitted	BCl_3 Cl_2 HCl NH_3	DCS HCl NH_3	BCl_3 C_2F_6 CF_4 CHF_3 Cl_2 HCl NH_3	BCl_3 Cl_2 HCl N_2O NF_3	Cl_2 HCl N_2O NH_3	BCl_3 Cl_2 DCS HCl NF_3 NH_3	Acetone Butyl Acetate Ethyl Lactate HMDS IPA Methyl Pyrollidone PGMEA	B_2H_6 C_2F_6 CF_4 CHF_3 DCS N_2O NH_3 PH_3 SiH_4	B_2H_6 C_2F_6 CF_4 CHF_3 PH_3 SiH_4	Cl_2 HCl N_2O NF_3 NH_3

Table 8.10 - Polar Grid Elevation Heights for Company E (m).

Distance (m)	50	100	250	500	750	1,000	2,000	3,000	4,000	5,000
Direction (°)										
45	200	200	190	190	190	190	170	140	150	120
90	200	200	200	190	190	180	200	200	210	220
135	200	200	200	200	200	190	210	220	230	240
180	200	200	200	200	190	200	200	220	230	270
225	200	200	200	200	200	200	190	190	200	220
270	200	200	210	200	200	200	210	170	160	150
315	200	200	210	190	180	170	160	150	120	140
360	200	200	200	190	180	180	190	160	180	180
Base Height										200

Polar grid co-ordinates centred on (0 , 0 .
From Ordnance Survey (1988).

Stack release rates were estimated by dividing the total release rate by the number of stacks from which a given gas is released, as shown in Table 8.11. Stack locations were approximated by placing them along the centre axis of each building unit, with the higher stacks towards the middle, in order to calculate the co-ordinates given in Table 8.9.

Table 8.11 - Stack Release Rates for Significant Air Emissions from Company E.

	No. of Stacks		Release Rate (g/s)			
Parameter	Q1-Q3	Q4	Q1	Q2	Q3	Q4
HCl	9	11	0.00077	0.00115	0.00269	0.00094
SiH_4	12	14	0.0027	0.0023	0.0026	0.0023
Cl_2	6	8	0.0074	0.0042	0.0085	0.0040
B_2H_6	8	10	0.000060	-	0.000066	0.001526
Xylene	3	3	-	0.116	0.101	-

Using the above data the model was run for each substance in each quarter to predict the location with the maximum average annual concentration. Table 8.12 shows the results for significant releases from Company E.

Table 8.12 - Predicted Concentrations in Air for Company E (ug / m^3).

	Period	Q1	Q2	Q3	Q4
Parameter	EQS / EAL (ug/m^3)				
HCl	7	0.01567	0.02350	0.05484	0.01861
SiH_4	7	0.13131	0.11097	0.12538	0.11045
CL_2	1.5	0.14479	0.08274	0.16548	0.07528
B_2H_6	1	0.00080	-	0.00087	0.02270

The table also shows the EQSs or EALs for the substances concerned. These are used to calculate the EQ for air (see Table 8.13), as described in section 2.3.3.

Table 8.13 - Environmental Quotients ($EQ_{(S)}$) and $EQ_{(Air)}$ for Company E.

Period Parameter	Q1	Q2	Q3	Q4
HCl	0.0022	0.0034	0.0078	0.0027
SiH_4	0.019	0.016	0.018	0.016
Cl_2	0.097	0.055	0.110	0.061
B_2H_6	0.00080	-	0.0087	0.02270
$EQ_{(Air)}$	0.11832	0.07437	0.13693	0.09131

8.3.2 Emissions to Water.

For emissions to riverine surface waters a mass balance model was used to estimate the dispersion of significant releases from Table 8.8. The Warn-Brew model looks at the distribution of river discharge and combines this with data on the distribution of the outfall discharge and pollutant concentrations, as described in section 3.3.2.

Table 8.14 - Flow Data for the Rotten Calder and Sewerage Works (l/s).

Parameter	River Discharge	Sewerage Discharge
Mean Flow (l/s)	791	194
Standard Deviation (l/s)	7.91 †	65

From SEPA 1996a). † From NRA (1993).

As a flow distribution curve was not available for the Rotten Calder, the river to which the effluent is discharged, the mean and standard deviation for river flow were used, as shown in Table 8.14. The standard deviation was estimated from the mean river flow, according to NRA (1993). The releases from Company E enter the Rotten Calder via a public sewage works, for which the discharge data is also provided (SEPA 1996a).

The model also requires the mean and standard deviation of the concentration of the pollutants rather than the release rates given in Table 8.8. The mean concentration was estimated using effluent discharge data and the mass emission data given in Table 8.4, with the standard deviations derived for each pollutant using the coefficient of variation for that pollutant over the year. The data used for the model is given in Table 8.15.

Table 8.15 - Effluent Concentration Data for Company E (ug/l).

	Average				Standard Deviation			
Paramete	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
NH^{4+}	5.09	3.13	2.23	0.94	3.12	1.92	1.37	0.58
Sn	4.81	11.12	4.00	6.52	2.31	5.35	1.93	3.14
Cd	0.49	0.82	0.51	0.63	0.12	0.20	0.13	0.16
Cu	0.96	1.31	0.79	1.36	0.24	0.33	0.20	0.34
Zn	0.53	0.78	0.57	0.70	0.09	0.13	0.10	0.12
Pb	0.94	1.07	0.79	1.01	0.12	0.14	0.10	0.13
Ni	0.73	0.53	-	0.55	0.19	0.14	-	0.15
As	0.55	0.53	-	0.55	0.09	0.09	-	0.09
S.S.	170.14	327.70	180.16	246.77	53.56	103.15	56.71	77.68
BOD	321.73	269.71	398.08	424.59	64.50	54.07	79.81	85.13

The predicted concentrations, which represent the location with the maximum annual average concentration, resulting from the significant releases to water are given in Table 8.16.

Table 8.16 - Predicted Concentrations in Water for Company E (ug/l).

	Period	Q1	Q2	Q3	Q4
Parameter	EQS / EAL (ug/l)				
NH^{4+}	19	0.00269	0.00166	0.00118	0.00050
As	50	0.00029	0.00028	-	0.00029
BOD	3,000	0.17034	0.14280	0.21077	0.22480
Cd	5	0.00026	0.00043	0.00027	0.00033
Cu	10	0.00051	0.00069	0.00042	0.00072
Pb	10	0.00050	0.00053	0.00042	0.00053
Ni	150	0.00039	0.00028	-	0.00029
S.S.	25,000	0.09008	0.17350	0.09539	0.13065
Sn	25	0.00255	0.00589	0.00212	0.00345
Zn	75	0.00028	0.00041	0.00030	0.00037

Table 8.16 also shows the EQSs or EAL for each substance, which are used to calculate the EQ for water in Table 8.17.

8.3.3 Emissions to Land.

Indirect emissions to land, via deposition from the air, occur for xylene. The ISCLT model was used to predict the deposition of this gas, with the data given in section 8.3.1, as described in section 3.3.1. The results from the model are shown below in Table 8.18, together with the EAL for xylene.

Table 8.17 - Environmental Quotients ($EQ_{(S)}$) and $EQ_{(Water)}$ for Company E.

Period	Q1	Q2	Q3	Q4
Parameter				
NH^{4+}	0.0001420	0.0000870	0.0000620	0.0000260
As	0.0000058	0.0000056	-	0.0000058
BOD	0.0000570	0.0000480	0.0000700	0.0000750
Cd	0.0000520	0.0000860	0.0000540	0.0000660
Cu	0.0000510	0.0000690	0.0000420	0.0000720
Pb	0.0000500	0.0000530	0.0000420	0.0000530
Ni	0.0000026	0.0000019	-	0.0000019
S.S.	0.0000036	0.0000069	0.0000038	0.0000052
Sn	0.0001020	0.0002360	0.0000850	0.0001380
Zn	0.0000037	0.0000055	0.0000040	0.0000049
$EQ_{(Water)}$	0.0004691	0.0005984	0.0003630	0.0004481

Table 8.18 - Predicted Deposition to Land for Company E (mg/m²/day).

	Period	Q1	Q2	Q3	Q4
Parameter	EAL(mg/m²/day)				
Xylene	14.4	-	0.86491	0.75256	-

The resulting EQ for land is given in Table 8.19.

Table 8.19 - Environmental Quotients ($EQ_{(S)}$) and $EQ_{(Land)}$ for Company E.

Period	Q1	Q2	Q3	Q4
Parameter				
Xylene	0.000	0.060	0.052	0.000
$EQ_{(Land)}$	0.000	0.060	0.052	0.000

8.3.4 The Integrated Environmental Index.

The EQs for air, water and land and the resulting IEI for Company E are shown in Table 8.20.

Table 8.20 - $EQ_{(Air)}$, $EQ_{(Water)}$, $EQ_{(Land)}$ and the IEI for Company E.

Period	Q1	Q2	Q3	Q4
Parameter				
$EQ_{(Air)}$	0.11832	0.07437	0.13693	0.09131
$EQ_{(Water)}$	0.0004691	0.0005984	0.0003630	0.0004481
$EQ_{(Land)}$	0.000	0.060	0.052	0.000
IEI	0.1187932	0.1350302	0.1895560	0.091765

8.4 The Total Environmental Potency Index.

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 8.1- Table 8.5.

Table 8.21 - Category Totals and TEPI for Company E.

Period	Q1	Q2	Q3	Q4
Category				
GWP	5,458,301.626	5,398,625.766	6,156,718.405	4,316,018.297
ODP	0.000	0.000	0.000	0.000
HTP	1,327.321	1,203.999	837.835	1,010.153
AETP	6,816.898	8,316.873	5,414.598	7,130.758
TETP	0.019	0.031	0.020	0.024
POCP	5,160.733	7,893.590	8,283.746	3,863.236
AP	1,681.657	1,217.456	823.069	989.642
NP	418.559	332.707	218.124	287.807
WH	7,414.200	5,367.600	3,628.800	4,363.200
LA	114,312	114,312	114,312	114,312
TEPI	5,595,433.011	5,537,270.022	6,290,236.596	4,447,975.118

Each of the substances covered by the TEPI is allocated a series of potency factors which describe its contribution to different environmental potency categories, as discussed in section 3.4. The category totals and TEPI from these emissions are given in Table 8.21.

In order to assess the effect of electricity use on the site's total potency in section 11.3.3, the usage data in Table 8.6 has been used to calculate the TEPI for electricity, based on the average UK generation mix (see Table 8.22). This data has not been included in the site totals being used for the comparative study.

Table 8.22 - TEPI for Electricity Use at Company E (UK Average).

Period Category	1	2	3	4
GWP	18,711,284	24,772,594	21,556,388	25,521,306
ODP	0	0	0	0
HTP	25,945	34,350	29,890	35,388
AETP	0	0	0	0
TETP	0	0	0	0
POCP	5,945	7,871	6,849	8,109
AP	111,564	147,704	128,528	152,168
NP	7,110	9,414	8,192	9,698
WH	207	275	239	283
LA	11	14	12	15
TEPI	18,862,067	24,972,221	21,730,099	25,726,967

CHAPTER NINE

Company F

Textiles

9.1 The Company.

Company F is a textile manufacturer taking part as a black box site. The company forms part of a large textile products group, manufacturing tights, primarily as home brands for the UK retail sector. The site is subject to LAAPC for its releases to air. The group produces an annual environmental report which is publicly available. At the time of the study the site did not have an environmental management standard, but it has since been accredited to BS7750. Environmental management at the site is carried out by an environmental projects officer, reporting to the safety manager. The site employs a total of 1,000 people.

9.2 Textile Manufacturing Process & Emissions.

Company F weaves and assembles tights in a variety of thicknesses and colours. The material flows associated with these processes are shown in Figure 9.1. Sections of tights are woven on machines and then trimmed and pressed together. Steam is used to heat the tights as part of this process and is generated in a gas fired boiler. Some tights are sent away to be coloured at an external dyer and returned for checking and packaging with the other products, before being dispatched to the client. Trimmed material and other wastes are removed by contractors for disposal or recycling.

9.2.1 Process Emissions.

Direct emissions consist of the combustion products from the generation of steam using natural gas. There are no process related emissions to water. Air emission data was not available from the company. These emissions were, therefore, estimated using emission factors and gas usage data. The calculation of

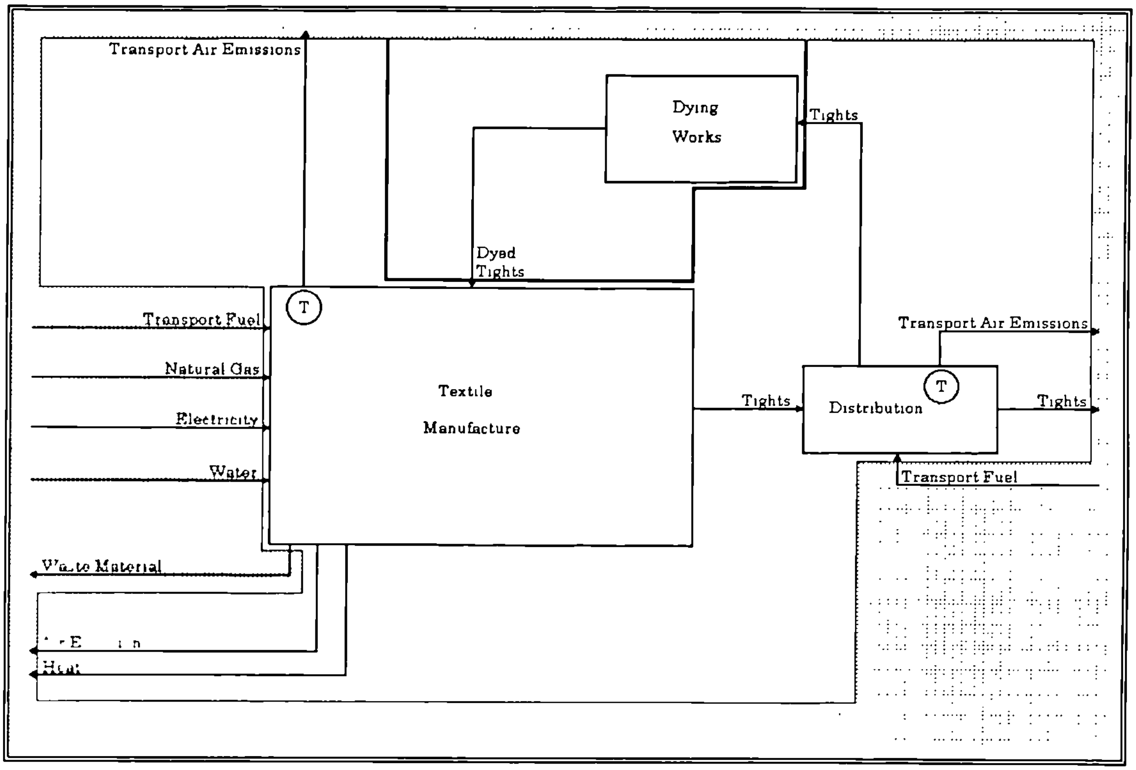


Figure 9.1 - The Boundaries and Material & Energy Flows for Company F.

these factors is explained in section 6.2.4. The resulting emission estimates are shown in Table 9.1.

Table 9.1 - Emissions to Air from Company F (Kg).

Parameter	CO_2	SO_2	NOx
Period			
7	1,012.987	0.009	0.885
8	825.363	0.008	0.721
9	1,435.657	0.013	1.255
10	1,549.974	0.014	1.355
11	2,000.025	0.018	1.748
12	1,318.912	0.012	1.153
1	2,453.872	0.023	2.145
2	1,873.261	0.017	1.637
3	2,478.453	0.023	2.166
4	2,051.801	0.019	1.793
5	2,122.743	0.020	1.855
6	1,379.214	0.013	1.205

9.2.2 Distribution.

The textile products manufactured at Company F are distributed to clients within the UK, using heavy goods vehicles for transport by road.

Table 9.2 - Distribution Emissions from Company F (Kg).

	Parameter	CO_2	CO	VOC	NOx	SO_2
	Road Factor(g/Km)	853	3.92	0.45	13.06	0.28
Period	Distance (Km)					
7	96,396	82,226	378	43	1,259	27
8	96,396	82,226	378	43	1,259	27
9	224,162	191,210	879	101	2,928	63
10	179,316	152,957	703	81	2,342	50
11	179,316	152,957	703	81	2,342	50
12	224,162	191,210	879	101	2,928	63
1	96,396	82,226	378	43	1,259	27
2	96,396	82,226	378	43	1,259	27
3	120,512	102,796	472	54	1,574	34
4	96,396	82,226	378	43	1,259	27
5	96,396	82,226	378	43	1,259	27
6	120,512	102,796	472	54	1,574	34

Emission factors from Gover et al. (1996).

9.2.2.1 Process Emissions.

Direct emissions occur primarily to air from this function. However, no data was available for these emissions. Data on the number of trips made to each client per month was, therefore, used to estimate expected emissions. The distance to each client was calculated using a route planner and combined with emission factors on 6 parameters to predict emissions to air from transport by road, according to Equation 7.2. The total monthly emissions from the distribution of textile products covered by the TEPI are given in Table 9.2.

9.2.3 Site Parameters.

A number of parameters used by the TEPI are relevant to all of the process and are best covered as a whole for the site.

9.2.3.1 Internal Transport.

Internal transport at the site is carried out primarily by diesel powered fork-lift trucks. Emissions from this function have been estimated using emission factors from Gover et al. (1996) and the amount of diesel used, as shown in Table 9.3.

Table 9.3 - Internal Transport Emissions from Company F (Kg).

Period	*Usage (ltrs)*	*Parameter*	CO_2	CO	HC	NOx	SO_2
		Emission Factor (g/ltr.)	2,592.23	12.91	3.20	13.50	0.87
7	25.2		65.324	0.325	0.081	0.340	0.022
8	25.2		65.324	0.325	0.081	0.340	0.022
9	31.5		81.655	0.407	0.101	0.425	0.027
10	25.2		65.324	0.325	0.081	0.340	0.022
11	25.2		65.324	0.325	0.081	0.340	0.022
12	31.5		81.655	0.407	0.101	0.425	0.027
1	25.2		65.324	0.325	0.081	0.340	0.022
2	25.2		65.324	0.325	0.081	0.340	0.022
3	31.5		81.655	0.407	0.101	0.425	0.027
4	25.2		65.324	0.325	0.081	0.340	0.022
5	25.2		65.324	0.325	0.081	0.340	0.022
6	31.5		81.655	0.407	0.101	0.425	0.027

Emission factors from Gover et al. (1996).

9.2.3.2 Heat Losses.

Heat losses from the boiler of the site were estimated, using a thermal efficiency of 85% (see Table 9.4). It is assumed that all the energy in the steam generated for the site is transferred as useful work.

Table 9.4 - Heat Losses from Company F (GJ).

Parameter Period	Energy In	Waste Heat	Parameter Period	Energy In	Waste Heat
7	18	3	1	45	7
8	15	2	2	34	5
9	26	4	3	45	7
10	28	4	4	37	6
11	37	5	5	39	6
12	24	4	6	25	4

9.2.3.3 Land Area.

The area of land owned by the site covers 21,381m^2. It is assumed that all of this land is covered by the site's operations.

9.2.3.4 Electricity Use.

Electricity is the primary source of energy for this site. Although the use of electricity has no direct environmental burden, it will be used to estimate the contribution of an indirect process on the company. The usage figures used to calculate this contribution, from the emissions of a variety of electricity generators, are given in Table 9.5.

Table 9.5 - Electricity Use at Company F (KWh).

Period	7	8	9	10	11	12
Electricity	1,450,655	1,363,890	1,266,745	1,207,090	1,407,730	1,029,305
Period	1	2	3	4	5	6
Electricity	1,228,511	1,089,820	1,196,120	1,097,045	1,101,005	1,101,005

9.3 The Integrated Environmental Index.

The IEI is only calculated for those substances released via point-sources. Internal transport and distribution emissions will, therefore, not be included the assessment. All releases are firstly tested for significance, as discussed in section 2.3.3. The required release rates have been calculated using the site running hours to give a monthly average. The release rates and significance limits for emissions to air are given in Table 9.6. Significant releases are shown in **bold** or underlined. There are no process releases to water. As there are no significant releases from Company F, no further modelling need be carried out. The IEI for this site, therefore, equals zero.

Table 9.6 - Air Release Rates & Limits for Company F (g/s).

Parameter Period	Running Hours	SO_2	NO_X
7	224	0.000012	0.0011
8	224	0.000009	0.0009
9	280	0.000013	0.0012
10	224	0.000018	0.0017
11	224	0.000023	0.0022
12	280	0.000012	0.0011
1	224	0.000028	0.0027
2	224	0.000021	0.0020
3	280	0.000023	0.0021
4	224	0.000024	0.0022
5	224	0.000024	0.0023
6	280	0.000013	0.0012
Air Limit		0.050000	0.1000
Land Limit		N/A	N/A

Bold = Significant release for air quality.
Underlined = Significant release for deposition to land.
Calculated for stack height of 10m from HMIP (1995b).

9.4 The Total Environmental Potency Index

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 9.1. Each of the substances covered by the TEPI is allocated a series of potency factors which describe its contribution to different environmental potency categories, as described in section 3.4. The category totals and TEPI from these emissions are given in Table 9.7. In order to assess the effect of electricity use on the site's total potency in section 11.3.3, the usage data in has been used to calculate the TEPI for electricity, based on the average UK generation mix (see Table 9.8). This data has not been included in the site totals used for the comparative study.

Table 9.7 - Category Totals & TEPI for Company F.

Period	7	8	9	10	11	12	1	2	3	4	5	6
Category												
GWP	83,304	83,116	192,727	154,572	155,022	192,610	84,745	84,164	105,356	84,343	84,414	104,257
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	332	332	772	617	617	772	332	332	415	332	332	415
AETP	0	0	0	0	0	0	0	0	0	0	0	0
TETP	0	0	0	0	0	0	0	0	0	0	0	0
POCP	63	63	147	117	117	147	63	63	79	63	63	79
AP	909	909	2,113	1,691	1,691	2,113	910	910	1,137	910	910	1,137
NP	164	164	381	305	305	381	164	164	205	164	164	205
WH	3	2	4	4	5	4	7	5	7	6	6	4
LA	21,381	21,381	21,381	21,381	21,381	21,381	21,381	21,381	21,381	21,381	21,381	21,381
TEPI	106,156	105,968	217,525	178,687	179,139	217,407	107,602	107,019	128,581	107,199	107,270	127,477

Table 9.8 - Category Totals & TEPI for Electricity Used at Company F (UK Average).

Period	7	8	9	10	11	12	1	2	3	4	5	6
Category												
GWP	944,454	887,966	824,719	785,880	916,508	670,133	799,827	709,531	778,738	714,235	716,813	716,813
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	1,310	1,231	1,144	1,090	1,271	929	1,109	984	1,080	990	994	994
AETP	0	0	0	0	0	0	0	0	0	0	0	0
TETP	0	0	0	0	0	0	0	0	0	0	0	0
POCP	300	282	262	250	291	213	254	225	247	227	228	228
AP	5,631	5,294	4,917	4,686	5,465	3,996	4,769	4,231	4,643	4,259	4,274	4,274
NP	359	337	313	299	348	255	304	270	296	271	272	272
WH	10	10	9	9	10	7	9	8	9	8	8	8
LA	0.54	0.51	0.47	0.45	0.52	0.38	0.46	0.41	0.45	0.41	0.41	0.41
TEPI	952,065	895,121	831,365	792,213	923,893	675,533	806,272	715,249	785,014	719,991	722,590	722,590

CHAPTER TEN

Company G

Food Products

10.1 The Company.

Company G is a food product manufacturer taking part as a grey box site. The company forms part of a group, owned by a larger multi-national consumer product company. The site produces a variety of yeast products for use in the food and drinks industries. The site is subject to IPC for its releases to air and water. It is not accredited to an environmental management standard, but the parent company produces an environmental report, which is publicly available. The company employs 172 people, from 4,467 within the group, and 380,000 within the parent company. Environmental matters are dealt with by an environmental manager, responsible to the operations manager.

10.2 The Food Products Processes & Emissions.

The food products manufacturing process has been divided into six sub-systems to help understand how they work, gather data and estimate emissions. These are: yeast preparation, yeast product manufacture, yeast extract manufacture, CMS manufacture, distribution, boiler plant and effluent treatment (see Figure 10.1). The processes and emissions associated with these sub-systems are discussed below.

10.2.1 Yeast Preparation.

The yeast preparation system grows and separates the yeast cultures for direct sales or use in the yeast product or extract systems. A 70g yeast culture is firstly fed with ammonia, molasses, and phosphoric acid, using air as a mixing agent (see Figure 10.1). From this process 1 tonne of molasses will provide approximately 150 Kg of yeast. This yeast is then given excess air, but no food, which makes the

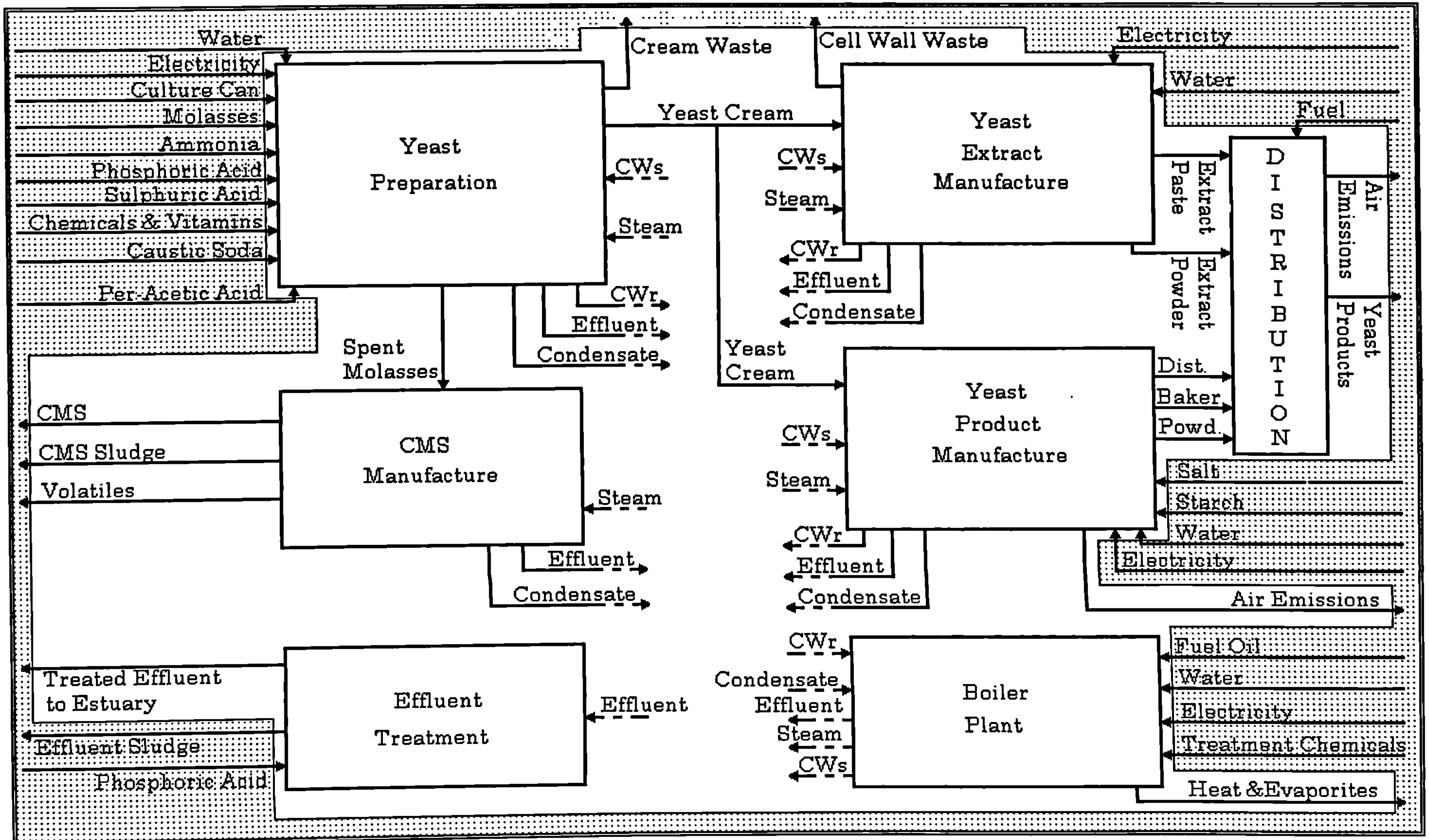


Figure 10.1 - The Boundaries, Sub-systems and Material & Energy Flows for Company G.

yeast remetabolise the alcohol, produced in reducing the molasses, into usable sugars and so increase the yield. The yeast is then fed with small shots of molasses and additives such as vitamins, to continue the growth process and maximise yeast production. Finally, the yeast and its nutrients are passed through a series of centrifugal separators, where the yeast cells are separated from the rest of the liquid and cleaned. The spent molasses from the first of these separators is removed to CMS manufacturing, with the remainder going to effluent treatment. The yeast cream produced is then stored for use in the yeast product or yeast extract system. Small samples are taken to test the quality of the yeast, with bad yeast either diverted to inactive products or transported off-site by a waste contractor. Cleaning of the tanks and pipes takes place between transfers and growing batches, using sodium hydroxide or per-acetic acid.

10.2.1.1 Process Emissions.

There are no known direct emissions from yeast preparation, although some gaseous emissions will exit with the air used to mix the yeast in the culture vessels.

Equation 10.1 - Calculation of EEF for Yeast Preparation at Company G.

$$
\begin{aligned}
EEF_{(YP)} &= 1 - \frac{\text{Dry Weight of Products Out}}{\text{Dry Weight of Products In}} \\
&= 1 - \frac{19{,}950{,}345 \text{ Tonnes}}{49{,}631{,}714 \text{ Tonnes}} \\
&= 1 - 0.4020 \\
&= 59.80\%
\end{aligned}
$$

Releases to water occur indirectly via the water utility system. These emissions, with the exception of BOD/COD, have been approximated using a mass balance model in section 10.2.6. To estimate how much of each product and its constituents has been incorporated into the yeast, material usage data has been used to estimate an Effluent Emission Factor ($EEF_{(YP)}$) for yeast preparation, according to Equation 10.1.

Equation 10.2 -Calculation of Effluent Use by CMS Manufacture for Company G

$$\text{CMS Usage} = \frac{\text{Dry Weight of CMS + Sludge Out}}{\text{Dry Weight of Molasses In}} = \frac{28{,}132{,}858 \text{ Tonnes}}{43{,}423{,}220 \text{ Tonnes}} = 64.79\%$$

$$\text{To Effluent Treatment} = 35.21\%$$

Not all of this effluent goes directly to the effluent treatment plant, however, with molasses from the first pass of the separators going to CMS manufacturing. To adjust the EEF to take account of this, data on the amount of molasses used and the quantity of CMS and CMS sludge produced, was used to calculate the proportion of molasses converted to CMS, as shown in Equation 10.2.

Equation 10.3 - Calculation of EEF for Yeast Preparation & CMS at Company G.

$$EEF_{(YC)} = 0.5980 * 0.3521 = 21.06\%$$

This proportion was assumed to hold for all the other materials used in yeast preparation and used to derive the EEF for yeast preparation and CMS ($EEF_{(YC)}$) as a whole, as shown in Equation 10.3.

This factor was then used to estimate the amount of each chemical used in yeast preparation which remains for effluent treatment. Any cleaning products used when the process is out of operation will have an EEF of 100%. The final emissions from the effluent treatment plant are given in section 10.2.6.

10.2.2 Yeast Product Manufacture.

The yeast product manufacture system produces bakers and distillers yeast, and autolised yeast from the cream yeast. The bakers and distillers yeast are manufactured using a filtering technique in which different forms of starch are used as the filter medium. Brine is added to the yeast cream in order to ensure the required moisture content of the yeast and the cream yeast liquid is then passed through a rotating drum coated in starch. The yeast and some of the starch are continually scraped from this drum and then passed through a collection and packaging machine. Any of the yeast that is below specification is used together with cream yeast to produce autolised yeast. In this process the yeast liquid is passed over a rotating drum heated with steam. The dried yeast is then scraped off the drum. Although the cream yeast contains some moisture, this is essentially a dry process, with no liquid effluent or wastes. The dried yeast is then bagged up for dispatch.

10.2.2.1 Process Emissions.

Direct emissions from yeast product manufacture only occur to air. However, these emissions are not monitored consistently and could not be estimated.

Indirect emissions occur via the effluent treatment plant. As part of the mass balance calculations in section 10.2.6, it has been assumed that all the yeast passing into the system passes out either as a bakers, distillers or autolised yeast product. The starch products used in manufacturing the yeast, are assumed to have a token EEF of 0.5%. Any cleaning products used will not be used while the process is running and have an EEF of 100%.

10.2.3 Yeast Extract Manufacture.

The yeast extract manufacture system produces liquid, paste and powder products for the flavouring and food industries. Cream yeast is firstly combined with salt to burst the cell walls. The cell wall debris is removed and taken away by a waste contractor. The yeast extract is then concentrated by evaporating away the water to produce yeast extract liquid, paste and powder.

10.2.3.1 Process Emissions.

There are no known direct emissions from this system, although indirect emissions do occur via the effluent treatment plant. These emissions have been estimated using a mass balance in section 10.2.6

Equation 10.4 - Calculation of EEF for Yeast Extract Manufacture at Company G.

$$
\begin{aligned}
EEF_{(YE)} &= 1 - \frac{\text{Dry Weight Out}}{\text{Dry Weight In}} \\
&= 1 - \frac{1,322.506 \text{ Tonnes}}{2,122.483 \text{ Tonnes}} \\
&= 1 - 0.6230 \\
&= 37.70\%
\end{aligned}
$$

To estimate the amount of each product incorporated in the yeast extract, the usage data for this system was used to derive an Effluent Emission Factor ($EEF_{(YE)}$) for yeast extract manufacture as shown in Equation 10.4. This factor was used to estimate the amount of each chemical emitted from effluent treatment in section 10.2.6, with any cleaning products having an EEF of 100%.

10.2.4 CMS Manufacture.

The CMS manufacture system converts the spent molasses and other constituents from the primary cycle of the centrifuge separator of the yeast into Concentrated Molasses Solubles (CMS). This is done through a process of distillation and evaporation in which steam from the power utility is continuously re-pressurised using electrical compressors. A waste sludge is produced as part of this process, and is removed by a waste contractor, with process water being returned to the power utilities for the pre-heating of water used in the generation of steam, before being released to effluent treatment.

10.2.4.1 Process Emissions.

Direct emissions to air from the CMS plant consist of volatile organic compounds, for which consistent data was not available. Indirect emissions occur via the effluent treatment plant. These releases have been estimated using a mass balance study in section 10.2.6. With limited data available to calculate effluent emission factors, the EEF for yeast preparation was calculated to take account of the releases from the CMS, as shown in section 10.2.1.

10.2.5 Boiler Plant.

The boiler plant provides steam for the site and cools the process water from the fermenters in the yeast preparation system using cooling towers. The steam is generated in three out of four boilers, with one on standby, using heavy fuel oil. Treated burn-water is used to generate the steam. The cascading water cooling towers, use a variety of cleaning and anti-bacterial agents which are added to the system at a constant rate.

10.2.5.1 Process Emissions.

Direct emissions from the boiler plant consist of the combustion products of the fuel burnt and water vapour from the cooling towers. With no air emission data available, estimates were calculated using fuel usage data and the emissions factors given in Table 4.2 and Table 4.7. For NOx emissions an emission factor from Walker et al. (1985) was used.

Table 10.1 - Emissions to Air from Fuel Combustion at Company G (Kg).

Parameter Period	CO_2	SO_2	NOx	V	Ni	Particulates
7	29,304,671	460,431	55,958	452	136	33,578
8	27,062,879	425,209	51,677	418	126	31,010
9	28,519,965	448,102	54,459	440	133	32,679
10	36,936,574	580,343	70,531	570	172	42,323
11	30,644,684	481,486	58,516	473	143	35,114
12	45,065,246	708,060	86,053	695	210	51,637
1	40,496,230	636,272	77,328	625	189	46,402
2	31,519,568	495,232	60,187	486	147	36,116
3	32,345,408	508,207	61,764	499	151	37,062
4	38,010,799	597,221	72,582	587	177	43,554
5	25,154,903	395,231	48,034	388	117	28,823
6	24,083,842	378,402	45,988	372	112	27,596

NOx emission factor of 6 66g/Kg of fuel used, from Walker et al. (1985).

Water vapour emissions are not covered by the indices, but the chemicals added are released to effluent treatment when the cooling water is replaced. These chemicals have been included in the mass balance calculations in section 10.2.6 using a EEF of 100%.

10.2.6 Effluent Treatment.

The primary function of the effluent treatment plant is the biological treatment of effluent from all the systems on site. These effluent streams are combined in a storage tank, where phosphoric acid is added as a nutrient. It is then passed onto two aeration tanks, where bacteria break down the dissolved organic matter in the effluent. The resulting mixture is then passed into two further settling tanks in

Table 10.2 - Emissions to Water from Company G (Kg).

Parameter	Ni	P	Va	PO_{4-}	N	NH^{4+}	Fe	Zn	Pb	BOD	COD
Period											
7	0.006	135	0.00027	231	7.08	27	1.03	0.116	0.013	141,219	265,491
8	0.005	118	0.00024	216	7.70	24	0.82	0.104	0.012	141,219	265,491
9	0.005	129	0.00018	242	0.69	26	0.69	0.107	0.010	176,523	331,864
10	0.004	180	0.00021	179	1.72	53	0.23	0.070	0.009	743,745	1,398,240
11	0.006	140	0.00026	228	0.00	29	0.71	0.115	0.010	1,051,076	1,976,023
12	0.005	133	0.00017	240	0.00	28	0.66	0.105	0.010	1,317,000	2,475,960
1	0.004	121	0.00025	193	1.72	51	0.27	0.083	0.009	688,147	1,293,716
2	0.006	143	0.00000	228	0.00	29	0.81	0.113	0.012	572,145	1,075,632
3	0.006	144	0.00024	260	0.00	30	0.99	0.122	0.014	224,045	421,204
4	0.007	174	0.00000	271	0.00	36	1.13	0.148	0.018	338,224	635,862
5	0.005	123	0.00000	219	0.00	24	0.84	0.106	0.011	218,699	411,155
6	0.005	108	0.00000	238	0.00	23	0.73	0.102	0.010	301,645	567,093

Table 10.2 contd. - Emissions to Water from Company G (Kg).

Parameter	Cu	Mg	As	Cd	Cr	Co	F	Mn	Hg	Phenol
Period										
7	0.037	0.013	0.016	0.0002754	0.012	0.461	0.525	0.009	0.0012	0.00000
8	0.032	0.014	0.014	0.0002455	0.011	0.461	0.470	0.007	0.0009	0.00000
9	0.029	0.012	0.013	0.0001874	0.011	0.576	0.474	0.006	0.0008	0.00000
10	0.015	0.007	0.007	0.0002172	0.007	0.461	0.329	0.002	0.0004	0.00000
11	0.031	0.012	0.013	0.0002619	0.012	0.461	0.516	0.006	0.0009	0.00000
12	0.029	0.016	0.012	0.0001691	0.011	0.576	0.462	0.005	0.0007	0.00000
1	0.017	0.007	0.008	0.0002559	0.008	0.461	0.387	0.002	0.0005	0.00000
2	0.033	0.014	0.014	0.0000029	0.011	0.460	0.472	0.007	0.0007	0.00000
3	0.038	0.020	0.017	0.0002394	0.012	0.576	0.544	0.008	0.0011	0.00000
4	0.045	0.019	0.020	0.0000058	0.015	0.460	0.618	0.009	0.0010	0.00013
5	0.032	0.010	0.014	0.0000029	0.011	0.460	0.442	0.007	0.0007	0.00013
6	0.030	0.008	0.013	0.0000000	0.010	0.575	0.426	0.006	0.0006	0.00025

which the bacteria and solid matter are settled out. The remaining effluent is then passed to estuarine surface waters via an outfall pipe. Sludge from the settling tanks is further gravity thickened before being de-watered in a belt press and removed by a waste contractor.

10.2.6.1 Process Emissions.

Direct emissions from effluent treatment take place to air and water. No data is available, however, on the releases of CO_2 and other gases that would be released to air. Direct emissions to water are measured using a limited number of parameters. Consistent measurements are only taken for pH, BOD/COD suspended solids and temperature. A theoretical estimate was, therefore, calculated for the quantity of each known product constituent emitted using a mass balance study (see section 3.6.3), with removal factors for yeast preparation, and product / extract manufacture processes in sections 10.2.1, 10.2.2, and 10.2.3. To take account of the effluent treatment plant a WTRF of 70%, based on past experience of the site, was used. The resulting estimates, together with the sampled data for COD and BOD, are given in Table 10.2.

10.2.7 Distribution.

The food products manufactured at Company G are distributed to clients and group companies world-wide, using heavy goods vehicles and sea going freight carriers.

10.2.7.1 Process Emissions.

Direct emissions primarily occur to air from this function. However, no data was available for these emissions. Data on the number of trips made to each client per

Table 10.3 - Distribution Emissions from Road Transport for Company G (Kg).

	Period	7	8	9	10	11	12	1	2	3	4	5	6
Distance (km)		204,513	154,367	201,063	213,788	195,449	161,819	238,946	186,338	161,234	209.183	155,070	136,698
Parameter	Emission Factor (g/km)												
CO_2	853	174,450	131,675	171,507	182,361	166,718	138,031	203,821	158,946	137,532	178,433	132,275	116,603
CO	3.92	802	605	788	838	766	634	937	730	632	820	608	536
NO_x	13.06	2,671	2,016	2,626	2,792	2,553	2,113	3,121	2,434	2,106	2,732	2,025	1,785
SO_2	0.28	57	43	56	60	55	45	67	52	45	59	43	38
PM	1.07	219	165	215	229	209	173	256	199	173	224	166	146
VOC	0.45	92	69	90	96	88	73	108	84	73	94	70	62

Emission Factors from Gover et al. (1996).

Table 10.4 - Distribution Emissions from Shipping Transport for Company G (Kg).

	Period	7	8	9	10	11	12	1	2	3	4	5	6
Kg.Km ($x10^6$)		11,353	5,355	6,934	5,573	8,669	6,885	11,102	10,577	16,619	10.520	8,970	10,477
Parameter	Em. Factor (g/km.kg)												
Air Emissions													
CO_2	0.0095	107,854.32	50,869.94	65,873.30	52,943.65	82,354.46	65,406.99	105,465.96	99,915.64	157,880.37	99,944.71	85,217.17	99,531.75
CO	0.00003	340.59	160.64	208.02	167.19	260.07	206.55	333.05	315.52	498.57	315.61	269.11	314.31
HC	0.00002	227.06	107.09	138.68	111.46	173.38	137.70	222.03	210.35	332.38	210.41	179.40	209.54
NO_x	0.00016	1,816.49	856.76	1,109.45	891.68	1,387.02	1,101.59	1,776.27	1,682.79	2,659.04	1,683.28	1,435.24	1,676.32
SO_2	0.00025	2,838.27	1,338.68	1,733.51	1,393.25	2,167.22	1,721.24	2,775.42	2,629.36	4,154.75	2,630.12	2,242.56	2,619.26
PM	0.00001	113.53	53.55	69.34	55.73	86.69	68.85	111.02	105.17	166.19	105.20	89.70	104.77
Pb	0.00000002	0.23	0.11	0.14	0.11	0.17	0.14	0.22	0.21	0.33	0.21	0.18	0.21
VOC	0.0000018	20.44	9.64	12.48	10.03	15.60	12.39	19.98	18.93	29.91	18.94	16.15	18.86
Water Emissions													
Cu	0.00000003	0.34	0.16	0.21	0.17	0.26	0.21	0.33	0.32	0.50	0.32	0.27	0.31
Oil	0.00094	10,671.90	5,033.45	6,517.99	5,238.64	8,148.76	6,471.85	10,435.58	9,886.39	15,621.85	9,889.27	8,432.01	9,848.40
Sn	0.00000003	0.34	0.16	0.21	0.17	0.26	0.21	0.33	0.32	0.50	0.32	0.27	0.31

Emission Factors from BMI et al. (1996).

month was, therefore, used to estimate expected emissions from road and sea distribution separately. The distance to each client was calculated using a route planner for distribution by road and a pesometer and atlas for distribution by sea. For road distribution this data was combined with emission factors from Gover et al. (1996) to estimate the emission of six parameters, according to Equation 7.1. For sea distribution this data was combined with emissions factors from BMI et al. (1996) to estimate the emission of nine parameters, according to Equation 7.2. The total monthly emissions from the distribution of food products covered by the TEPI are given in Table 10.3 and Table 10.4.

10.2.8 Site Parameters.

A number of parameters used by TEPI are relevant to all of the processes and are best covered as a whole for the site.

10.2.8.1 Internal Transport.

There are no direct or indirect emissions from internal transport at Company G.

10.2.8.2 Heat Losses.

Heat losses from the site were estimated for the boiler plant of the site only, using an efficiency of 85% (see Table 10.5). It is assumed that all the energy in the steam used on the site is transferred as useful work.

Table 10.5 - Heat Losses from Company G (GJ).

Period	Energy In	Heat Loss	Period	Energy In	Heat Loss
7	345.324	51.799	1	477.204	71.581
8	318.906	47.836	2	371.424	55.714
9	336.077	50.411	3	381.155	57.173
10	435.257	65.289	4	447.916	67.187
11	361.114	54.167	5	296.423	44.463
12	531.045	79.657	6	283.802	42.570

10.2.8.3 Land Area.

The area of land owned by the site covers 56,900m^2. It is assumed that all of this land is covered by the site's operations.

10.2.8.4 Electricity Use.

Electricity is the primary source of energy for this site. Although the use of electricity has no direct environmental burden, it will be used to estimate the contribution of an indirect process on the company. The usage figures used to calculate this contribution, from the emissions of a variety of electricity generators, are given in Table 10.6.

Table 10.6 - Electricity Use at Company G (KWh).

Period	7	8	9	10	11	12
Usage	5,246,349	2,368,619	4,166,200	4,201,803	11,666,879	4,093,946
Period	1	2	3	4	5	6
Usage	4,690,200	4,047,800	4,086,200	4,889,600	3,558,300	3,460,561

10.3 The Integrated Environmental Index.

The IEI is only calculated for those substances released via point-sources. Distribution emissions will, therefore, not be included in the assessment. All releases are firstly tested for significance, as discussed in section 2.3.3. The required release rates have been calculated using the site running hours to give a monthly average. The release rates and significance limits for emissions to air are given in Table 10.8 and in Table 10.7 for water. Significant releases are shown in **bold** or underlined.

For those substances released at a significant rate during a given month, a more detailed assessment must be carried out, using the modelling techniques described in section 3.3.

Table 10.7 - Water Release Rates & Limits for Company G (ug/s).

Parameter	Cu	As	Cd	Cr	Hg	Ni	Va	NH4+	Fe	Zn	Pb	BOD
Period												
7	15.38	6.79	0.114	4.87	0.49	2.49	0.111	**11,168**	439	**2,130**	186.9	58,374,069
8	13.14	5.72	0.101	4.35	0.39	2.23	0.100	**9,846**	357	**3,375**	145.1	58,374,069
9	9.73	4.15	0.062	3.57	0.25	1.82	0.061	**8,684**	239	35	96.3	58,374,069
10	6.07	3.05	0.090	2.92	0.17	1.50	0.088	**21,725**	103	29	37.1	307,434,150
11	12.73	5.40	0.108	4.79	0.36	2.45	0.107	**12,033**	308	47	124.1	434,472,531
12	9.52	4.06	0.056	3.49	0.23	1.77	0.055	**9,347**	232	35	86.4	435,515,904
1	7.15	3.40	0.106	3.47	0.20	1.79	0.104	**21,108**	118	34	43.9	284,452,316
2	13.57	5.85	0.001	4.67	0.28	2.33	0.000	**12,028**	349	47	141.4	236,501,537
3	12.64	5.48	0.079	4.08	0.35	2.08	0.078	**9,839**	345	40	139.0	74,088,830
4	18.65	8.27	0.002	6.10	0.41	3.05	0.000	**14,865**	490	**16,720**	201.2	139,808,392
5	13.36	5.84	0.001	4.37	0.31	2.19	0.000	**9,953**	360	44	154.4	90,401,478
6	9.76	4.25	0.000	3.36	0.21	1.68	0.000	**7,624**	250	34	107.9	99,750,325
Limit	178.92	894.60	89.460	536.76	10.74	1,073.52	3,578.400	507	35,784	1,431	894.6	N/A

Bold = Significant release for water quality.
Limits calculated for nominal flow rate of 17.892 m^3/s from HMIP (1995b).
Nominal flow rate from SEPA (1996d,e,g,h).

Table 10.8 - Air Release Rates & Limits for Company G (g/s).

Parameter Period	Running Hours	SO_2	NO_X	Ni	Particulates
7	672	**190.324**	**23.131**	**0.056**	**13.880**
8	672	**175.764**	**21.361**	**0.052**	**12.818**
9	840	**148.182**	**18.009**	**0.044**	**10.807**
10	672	**239.890**	**29.155**	**0.071**	**17.495**
11	672	**199.027**	**24.188**	**0.059**	**14.515**
12	840	**234.147**	**28.457**	**0.069**	**17.076**
1	672	**263.009**	**31.964**	**0.078**	**19.181**
2	672	**204.709**	**24.879**	**0.061**	**14.929**
3	840	**168.058**	**20.425**	**0.050**	**12.256**
4	672	**246.867**	**30.002**	**0.073**	**18.003**
5	672	**163.373**	**19.855**	**0.048**	**11.914**
6	840	**125.133**	**15.208**	**0.037**	**9.126**
Air Limit		0.550	0.600	0.00030	0.400
Land Limit		N/A	N/A	0.013	N/A

Bold = Significant release for air quality.
Underlined = Significant release for deposition to land.
Limits calculated for stack height of 23m from HMIP (1995b).

10.3.1 Emissions to Air.

For releases to air the ISCLT model combines meteorological and topographic data with technical data to predict the dispersion of significant releases from Table 10.8. The technical data for the site is given in Table 10.9.

Table 10.9 - Technical Data for Air Emissions from Company G.

Parameter	Boilers 1	Boiler 2	Boiler 3
Stack Height (m)	27	27	23
Exit Diameter (m)	1.33	1.33	0.87
Exit Velocity (m/s)	15	15	15
Exit Temperature (°C)	202	202	229
X Co-ordinate (m)	0	0	0
Y Co-ordinate (m)	0	10	20

Meteorological data from Turnhouse was used (Meteorological Office 1995c), with topographic data derived from local Ordnance Survey (1981 & 1987b) maps (see Table 10.10).

Using the above data the model was run for each substance in each month to predict the location with the maximum average annual concentration.

Table 10.10 - Polar Grid Elevation Heights For Company G (m).

Distance (m)	50	250	500	750	1,000	2,000	3,000	4,000	5,000
Direction (°)									
45	10	10	10	10	15	400	365	400	615
90	10	10	10	10	10	10	10	10	10
135	10	10	10	10	30	60	65	50	20
180	10	10	10	15	20	25	5	5	5
225	10	10	10	10	10	10	10	5	5
270	10	10	10	10	10	10	10	10	25
315	10	10	10	25	100	225	200	260	245
360	10	10	15	75	200	340	405	525	475
Base Height									10

Polar grid co-ordinates centred on (0 , 0).
From Ordnance Survey (1981 & 1987b).

Table 10.11 shows the results for significant releases from Company G. The table also shows the EQSs or EALs for the substances concerned. These are used to calculate the EQ for air (see Table 10.12), as described in section 2.3.3. In the BPEO methodology (HMIP 1995b) the EQS for NOx is given, not as an annual average, but as a 98th percentile. As the meteorological data required to calculate 98th percentile values was not available, the annual average limit value for NOx was used as a substitute.

10.3.2 Emissions to Water.

For emissions to estuarine surface waters a mass balance model was used to estimate the dispersion of significant releases from Table 10.7. The model calculates the predicted concentrations at the outfall, and at points up and downstream of it, using data on the dimensions, discharge and salinity of those points in the estuary, as described in section 3.3.3.

Table 10.11 - Predicted Concentrations in Air for Company G (ug/m³).

Period Parameter.	EQS / EAL (ug/m³)	7	8	9	10	11	12	1	2	3	4	5	6
SO_2	80	82.693	76.367	64.383	104.229	86.474	101.734	114.274	88.943	73.019	107.261	70.984	54.369
NO_x	50	10.050	9.281	7.825	12.667	10.509	12.364	13.888	10.809	8.874	13.036	8.627	6.608
Ni	0.2	0.025	0.023	0.019	0.031	0.026	0.030	0.034	0.026	0.022	0.032	0.021	0.016
Parts.	80	6.031	5.570	4.695	7.602	6.306	7.419	8.334	6.486	5.325	7.822	5.176	3.965

Table 10.12 - Environmental Quotients ($EQ_{(Si)}$) and $EQ_{(Air)}$ for Company G.

Period Parameter	7	8	9	10	11	12	1	2	3	4	5	6
SO_2	1.034	0.955	0.805	1.303	1.081	1.272	1.428	1.112	0.913	1.341	0.887	0.680
NO_x	0.201	0.186	0.156	0.253	0.210	0.247	0.278	0.216	0.177	0.261	0.173	0.132
Ni	0.123	0.113	0.095	0.154	0.128	0.151	0.169	0.132	0.108	0.159	0.105	0.081
Parts.	0.075	0.070	0.059	0.095	0.079	0.093	0.104	0.081	0.067	0.098	0.065	0.050
$EQ_{(Air)}$	1.433	1.323	1.115	1.806	1.498	1.762	1.980	1.541	1.265	1.858	1.230	0.942

The physical data for the measurement points within the Forth estuary used in the model is given in Table 10.13.

Table 10.13 - Physical Data for Forth Estuary at Company G.

Parameter	Upstream	Outfall	Downstream
Estuary Salinity (ppt) †	6.31	7.44	9.70
River Discharge (m^3/s) ‡	62.51	62.51	62.51
Cross-Sectional Area (m^2) ¶	1,065	972	1 348
Dist. To Estuary Mouth (m) •	29,500	29,000	28,000
Nominal Flow Rate (m^3/s) ‡			17.892
Sea Water Salinity (ppt) |			33 75

† From SEPA (1995). ‡ From SEPA (1996d,e,g,h). ¶ From Admiralty (1988).
• From Ordnance Survey (1981 & 1987b). | From North Sea Task Force (1993).

Estuary salinity data for the point of discharge was obtained from SEPA (1995) and used to derive upstream and downstream salinity using the salinity gradients from Webb and Metcalfe (1987). River discharge data was obtained for the Forth and the tributaries upstream of the measurement points (SEPA 1996d,e,g,h). The cross-sectional areas were derived from an Admiralty (1988) map and represent the average of the areas at the Lowest Astronomical Tide and Mean High Water Spring. The distance to the estuary mouth was calculated from an Ordnance Survey (1976) map, using the official estuarine limit set at the 34 Easting. Sea water salinity data was obtained from (North Sea Task Force 1993).

The above data was used to calculate the predicted environmental concentrations shown in Table 10.14. Concentrations have also been calculated for BOD, which presently has no EQS or EAL within the IEI for estuarine releases, using the EAL for riverine releases. The results will be used later as BOD is known to be a major environmental burden from the site. The table shows the EQSs or EALs for each substances, which are used to calculate the EQ for water in Table 10.15. Separate EQs have been worked out for BOD.

Table 10.14 - Predicted Environmental Concentrations for Releases to Water from Company G (ug/l).

Period / Parameter	EQS / EAL (ug/l)	7	8	9	10	11	12	1	2	3	4	5	6
NH^{4+}	21	0.139	0.123	0.108	0.271	0.150	0.117	0.263	0.150	0.123	0.185	0.124	0.095
Zn	40	0.027	0.042	-	-	-	-	-	-	-	0.208	-	
BOD	3000	933	933	933	4,915	6,946	6,963	4,548	3,781	1,184	2,235	1,445	1,595

Table 10.15 - Environmental Quotients (EQ_{s}) and EQ_{Water} for Company G.

Period / Parameter	7	8	9	10	11	12	1	2	3	4	5	6
NH^{4+}	0.007	0.006	0.005	0.013	0.007	0.006	0.013	0.007	0.006	0.009	0.006	0.005
Zn	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000
$EQ_{(Water)}$	0.007	0.007	0.005	0.013	0.007	0.006	0.013	0.007	0.006	0.014	0.006	0.005
BOD (†)	0.311	0.311	0.311	1.638	2.315	2.321	1.516	1.260	0.395	0.745	0.482	0.532
$EQ_{(Water)}$ (†)	0.318	0.318	0.316	1.651	2.322	2.326	1.528	1.267	0.401	0.759	0.488	0.536

Table 10.16 - Predicted Deposition Rates to Land from Company G (mg/m²/day).

Period Parameter	EAL (mg/m²/day)	7	8	9	10	11	12	1	2	3	4	5	6
Ni	0.2	0.004	0.004	0.003	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.003	0.003

Table 10.17 - Environmental Quotients (EQ s) & EQ Land) for Company G.

Period Parameter	7	8	9	10	11	12	1	2	3	4	5	6
Ni	0.020	0.018	0.015	0.025	0.021	0.024	0.027	0.021	0.018	0.026	0.017	0.013
$EQ_{(Land)}$	0.020	0.018	0.015	0.025	0.021	0.024	0.027	0.021	0.018	0.026	0.017	0.013

10.3.3 Emissions to Land.

Company G has no direct releases to land. Indirect emissions, via deposition from the air, occur for nickel. The ISCLT model was used to predict the deposition of this metal, with the data given in section 10.2.5, as described in section 3.3.1. The results from the model are shown below in Table 10.16, with the EAL for nickel. The resulting EQ for land is given in Table 10.17.

10.3.4 The Integrated Environmental Index.

The EQs for air, water and land, and the resulting IEI for Company G are shown in Table 10.18. A separate calculation has been made to include the BOD parameter.

Table 10.18 - EQ_{Air}, EQ_{Water}, $EQ_{Land)}$ and the IEI for Company G.

Period	EQ_{Air}	$EQ_{Water)}$	$EQ_{(Water)}$ †	$EQ_{Land)}$	IEI	IEI †
7	1.433	0.007	0.318	0.020	1.460	1.771
8	1.323	0.007	0.318	0.018	1.348	1.659
9	1.115	0.005	0.316	0.015	1.136	1.447
10	1.806	0.013	1.651	0.025	1.844	3.482
11	1.498	0.007	2.322	0.021	1.526	3.841
12	1.762	0.006	2.326	0.024	1.792	4.113
1	1.980	0.013	1.528	0.027	2.020	3.536
2	1.541	0.007	1.267	0.021	1.569	2.830
3	1.265	0.006	0.401	0.018	1.288	1.683
4	1.858	0.014	0.759	0.026	1.898	2.643
5	1.230	0.006	0.488	0.017	1.253	1.734
6	0.942	0.005	0.536	0.013	0.959	1.491

† Including BOD emissions.

10.4 The Total Environmental Potency Index.

The TEPI is calculated for all releases directly to air, water and land from the site using the emission totals given in Table 10.1 - Table 10.5. Each of the substances covered by the TEPI is allocated a series of potency factors which describe its contribution to different environmental potency categories, as discussed in section 3.4. The category totals and TEPI from these emissions are given in Table 10.19.

Table 10.19 - Category Totals and TEPI for all Emissions from Company G.

Period Cat.	7	8	9	10	11	12	1	2	3	4	5	6
GWP	29,586,975	27,245,423	28,757,345	37,171,878	30,893,756	45,268,684	40,805,516	31,778,430	32,640,821	38,289.176	25,372,395	24,299,977
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	3,658,717	3,371,381	3,554,860	4,599,105	3,821,360	5,610,557	5,049,352	3,932,676	4,043,921	4,739,488	3,139,447	3,008,413
AETP	16,605	15,592	15,678	20,162	16,840	24,637	22,122	17,296	17,830	24,337	13,849	13,264
TETP	229,446,349	211,891,415	223,298,238	289,190,899	239,934,367	352,835,008	317,062,196	246,783,024	253,253,266	297,607,038	196,952,544	188,566,312
POCP	24,005	22,054	23,290	30,071	25,033	36,626	33,062	25,767	26,527	31,025	20,579	19,729
AP	505,638	464,775	490,628	633,746	527,427	772,313	696,671	542,925	558,977	653,808	433,563	415,675
NP	14,353	13,520	15,514	41,156	52,257	66,731	39,733	32,697	18,625	24,813	16,344	19,480
WH	52	48	50	65	54	80	72	56	57	67	44	43
LA	56,900	56,900	56,900	56,900	56,900	56,900	56,900	56,900	56,900	56,900	56,900	56,900
TEPI	263,309,594	243,081,108	256,212,502	331,743,984	275,327,995	404,671,538	363,765,625	283,169,771	290,616,924	341,426,652	226,005,664	216,399,792

Table 10.20 - Category Totals and TEPI for Electricity Used at Company G (UK Average).

Period	7	8	9	10	11	12	1	2	3	4	5	6
Cat.												
GWP	2,310,069	2,356,163	2,712,420	2,183,048	2,983,128	2,480,580	3,053,572	2,635,335	2,660,336	3,183,392	2,316,644	2,275,433
ODP	0	0	0	0	0	0	0	0	0	0	0	0
HTP	3,203	3,267	3,761	3,027	4,136	3,440	4,234	3,654	3,689	4,414	3,212	3,155
AETP	0	0	0	0	0	0	0	0	0	0	0	0
TETP	0	0	0	0	0	0	0	0	0	0	0	0
POCP	734	749	862	694	948	788	970	837	845	1,011	736	723
AP	13,774	14,048	16,173	13,016	17,787	14,790	18,207	15,713	15,862	18,981	13,813	13,567
NP	878	895	1,031	830	1,134	943	1,160	1,001	1,011	1,210	880	865
WH	26	26	30	24	33	27	34	29	29	35	26	25
LA	1	1	2	1	2	1	2	2	2	2	1	1
TEPI	2,328,684	2,375,150	2,734,278	2,200,640	3,007,167	2,500,569	3,078,179	2,656,572	2,681,774	3,209,045	2,335,313	2,293,769

In order to assess the effect of electricity use on the site's total potency in section 11.3, the usage data in Table 10.6 has been used to calculate the TEPI for electricity, based on the average UK generation mix (see Table 10.20). This data is not included in the site totals being used for the comparative study.

CHAPTER ELEVEN

Results and Analysis

The IEI and TEPI

11.1 Introduction.

This chapter presents the results obtained by analysing the data from Chapters 4 to 10 using the methods described in section 3.7. It begins with the site variability issues, followed by the process data results for the companies themselves and the sectors within which they operate.

11.2 Site Variability.

The effect of site variability on the IEI is assessed by comparing it with the TEPI to establish the potential interchangeability of the two indices. The potential use of the TEPI as a site application tool is also assessed. This has been done on a site by site basis and for all the sites as a whole. At the individual sites the IEI and TEPI might be expected to follow a similar pattern where the environmental capacity available is similar to that of the generic world of the TEPI. This may not be the case for sites with restricted capacity. It is these sites that may significantly affect the overall relationship between the two indices.

The IEI and TEPI are compared graphically and using *Spearman's Rho rank test* for independence (see section 3.7.1). This rank test on the TEPI values will show whether the differences in scale of the two indices may be affecting the results obtained. A second rank test uses the ranked category totals to assess whether the additive approach used in the TEPI may be affecting the results obtained. As the orders of magnitude of the category totals are different, due to inherent differences in potency factors, limiting the assessment to the actual categories means that different results will be obtained where one category is making the TEPI insensitive to significant changes in another.

The effect of site location on the two indices is also tested by looking at the sensitivity of the two indices to changes in the parameters covered. This will show up any differences between the environmental burdens covered by the indices. The sensitivity analysis on the TEPI will be backed up using the average change across its constituent categories, again to assess the possible influence of the additive approach taken (see section 3.7.1). The sensitivity analysis will only be carried out on a site by site basis.

Finally, the potential use of the TEPI as an alternative site application tool, as a substitute to the IEI for ranking different process options, will be assessed using the correlation coefficient for the ranked index values, using the TEPI categories to back up the results obtained (see section 3.7.1).

11.2.1 Intra-Company Comparisons.

The comparisons between the IEI and TEPI within the individual companies show a range of different results for the correlation coefficients and rank tests for independence.

Table 11.1 shows the correlation coefficients of the monthly IEI and TEPI results calculated for each of the companies A to G and the critical value for linearity based on the number of data points used. The r-values in **bold** indicate a significant results.

Table 11.1 - Correlation Coefficient between IEI and TEPI for Companies A to G.

Company	A	B	C	C*	D	E	F	G	G*
Crit. Val.	0.497	0.497	0.497	0.497	0.497	0.900	N/A	0.497	0.497
r	-0.051	**0.639**	**0.898**	**0.602**	0.460	**0.923**	N/A	**0.868**	**0.787**

* BOD included for calculation of IEI.

Table 11.2 shows the results of the rank test for independence, giving the critical values for the students t-distribution at 95%, $t_{0.95,n-2}$, for each of the companies followed by the corresponding test statistic using the TEPI (T_R) and its ranked categories ($T_R^{\#}$). From these the null hypothesis of independence is accepted or rejected.

Table 11.2 - Results from Spearman's Rho Rank Test for Independence.

Comp.	A	B	C	C*	D	E	F	G	G*
$t_{0.95,n-2}$	±1.81	±1.81	±1.81	±1.81	±1.81	±2.92	N/A	±1.81	±1.81
T_R	1.63	2.38	3.81	2.42	1.37	1.89	N/A	5.33	3.57
H_0	Accept	Reject	Reject	Reject	Accept	Accept	Accept	Reject	Reject
$T_R^{\#}$	8.10	4.30	3.45	1.90	1.71	-0.29	N/A	5.33	3.57
$H_0^{\#}$	Reject	Reject	Reject	Reject	Accept	Accept	Accept	Reject	Reject

* BOD included for calculation of IEI.
$^\#$ Analysis made using ranked TEPI categories.

Table 11.3 shows the correlation coefficients between the ranked IEI and both the ranked TEPI (r) and its ranked categories ($r^{\#}$), together with the critical value for each site.

Table 11.3 - Correlation Coefficients for Ranked IEI and TEPI values.

Company	A	B	C	C*	D	E	F	G	G*
Crit. Val.	0.497	0.497	0.497	0.497	0.497	0.900	N/A	0.497	0.497
r	0.161	**0.601**	**0.769**	**0.608**	0.399	**0.800**	N/A	**0.860**	**0.748**
$r^{\#}$	**0.629**	**0.806**	**0.738**	**0.515**	0.476	-0.200	N/A	**0.860**	**0.748**

* BOD included for calculation of IEI.
$^\#$ Analysis made using ranked TEPI categories.

Company A.

The monthly IEI and TEPI values for Company A, a power station, suggest a random independent relationship between the two indices, as shown in Figure 11.1. This is influenced strongly by three higher values to the right and bottom of the graph, which correspond to a month with unusually low emissions of carbon dioxide, and two months with high emission rates of NO_X (see section 4.2.2). As a result the data has a low insignificant correlation coefficient, r, of -0.1 (see Table 11.1). This shows there is no linear relationship between the two indices.

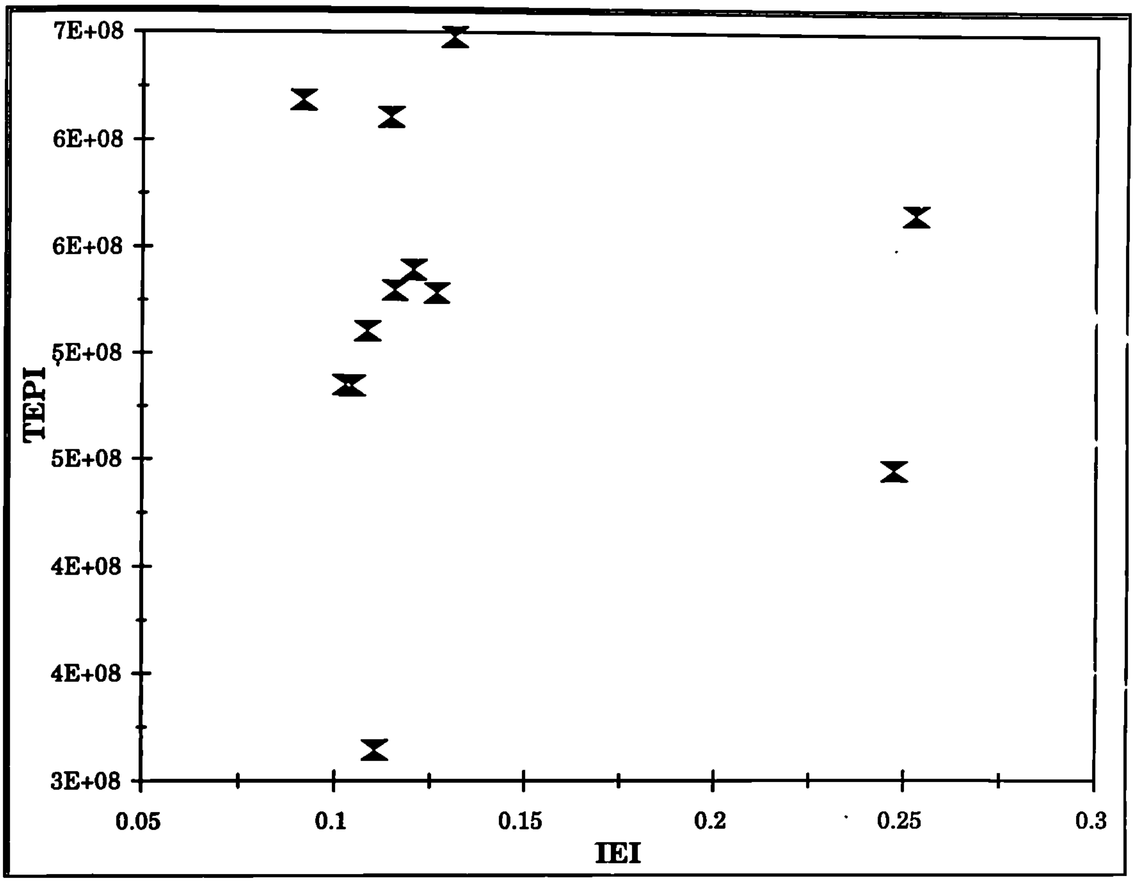


Figure 11.1 - Monthly Values of IEI against TEPI for Company A.

The rank test for independence using the TEPI supports this (see Table 11.2), but not when the ranked categories are used. The above results suggest that the IEI and TEPI cannot be used interchangeably at this site, but that the present additive approach used in the TEPI may be contributing to this disparity.

With no restrictions on environmental capacity present at the site, a linear relationship would have been expected. The low correlation coefficient obtained may be due to differences in the parameters covered by the indices. As the IEI presently has no significance limits for releases to coastal waters, these may be affecting the TEPI while the IEI remains unchanged. A sensitivity analysis of the IEI at Company A shows the index is dominated by emissions of NO_x. This is due to a high contribution to the fuel mix by gas. Figure 11.2 shows the percentage change in the IEI for a 5, 10 and 50% increase in the parameters shown.

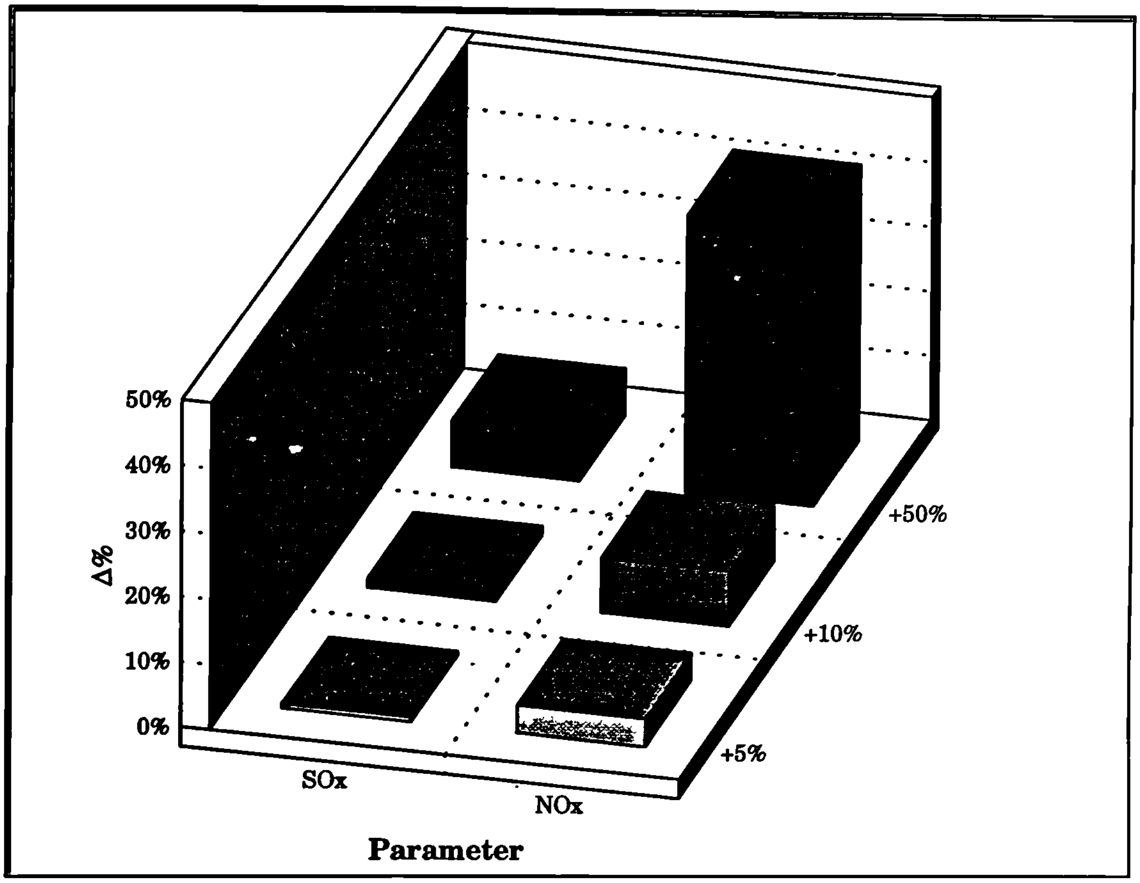


Figure 11.2 - Sensitivity of IEI to Increases in Emissions from Company A.

The TEPI is also dominated by releases to air, but is most sensitive to carbon dioxide emissions. The front row in Figure 11.3 shows the percentage change in the TEPI for a 50% increase its parameters.

The exclusion of carbon dioxide from the IEI may explain the very low correlation coefficient obtained, as the indices are driven by different emissions. Despite this some form of relationship might still have been expected, given that carbon dioxide and NOx will both be correlated to the amount of gas burnt. Although the exclusion of carbon dioxide from the IEI may be affecting the relationship between the indices, the outlying values in Figure 11.1 are caused by changes in NOx emissions. These are not picked up by the TEPI, and carbon dioxide emissions do not increase proportionally in these two cases.

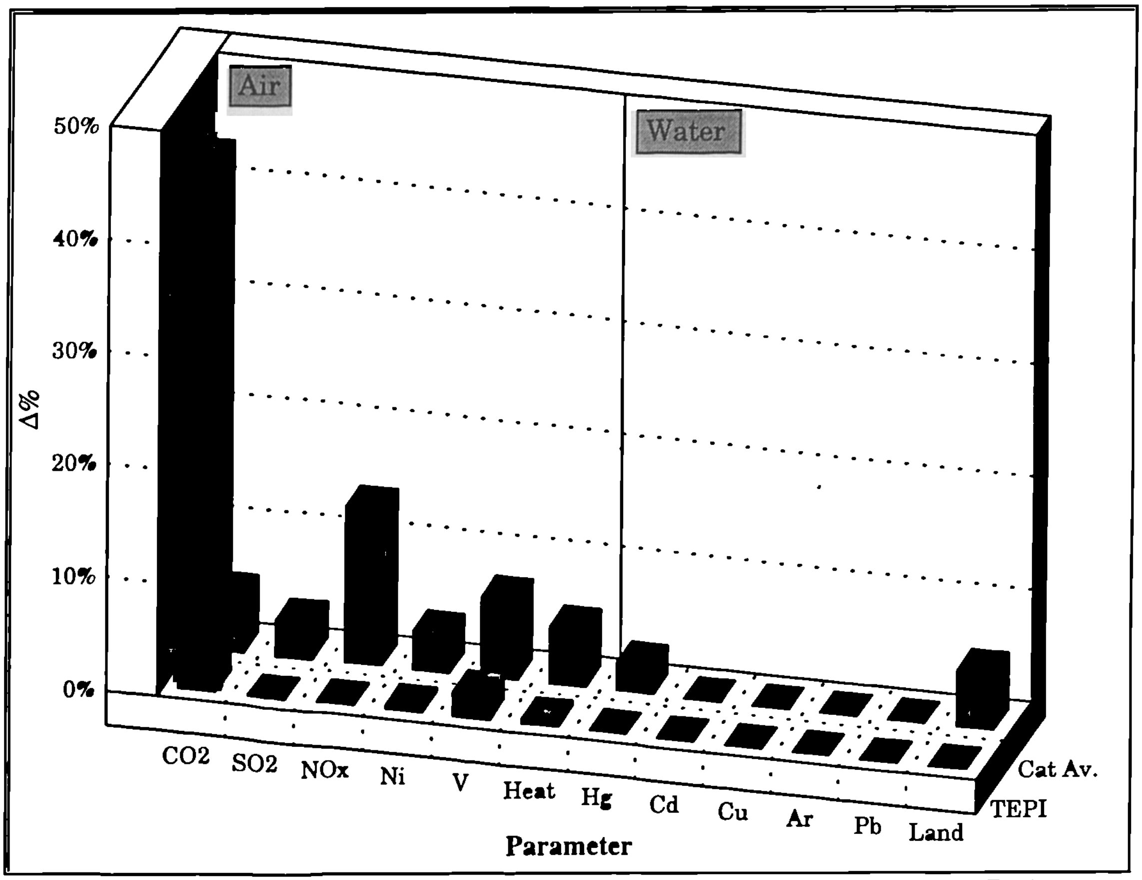


Figure 11.3 - Sensitivity of TEPI and its Categories to a 50% Increase in Emissions.

The fuel mix used at the site can, therefore, result in disproportionate increases in the amount of NOx and CO_2 released.

The rejection of independence by the ranked categories in Table 11.2 suggests that the additive approach used in the TEPI may also be contributing to the problem. The average sensitivity of the categories supports this, more closely matching the burdens expected from the site, especially for NOx. The back row in Figure 11.3 shows the average percentage change for a 50% increase in the parameters across the TEPI categories. This shows that NOx emissions have a large effect across the different categories, followed by carbon dioxide and vanadium.

At Company A the indices cannot be used interchangeably in their present state. This is due both to the exclusion of global parameters from the IEI, and the disproportionate effect of the greenhouse effect category on the TEPI. Consequently, changes in the fuel mix at the site have very disparate effects on the two indices.

The potential use of the TEPI as a process option ranking tool was influenced in a similar way to the above results. The ranked IEI and TEPI values give a low insignificant correlation coefficient of 0.2, which becomes significant (r = 0.6) when the ranked categories are used (see Table 11.3). There may, therefore, be a role for using the TEPI categories as a site application tool.

Company B.

Comparison of the monthly IEI and TEPI values for Company B indicates the linear relationship shown by the plot in Figure 11.4. The relationship is influenced primarily by the high index value, which corresponds to increased emissions of

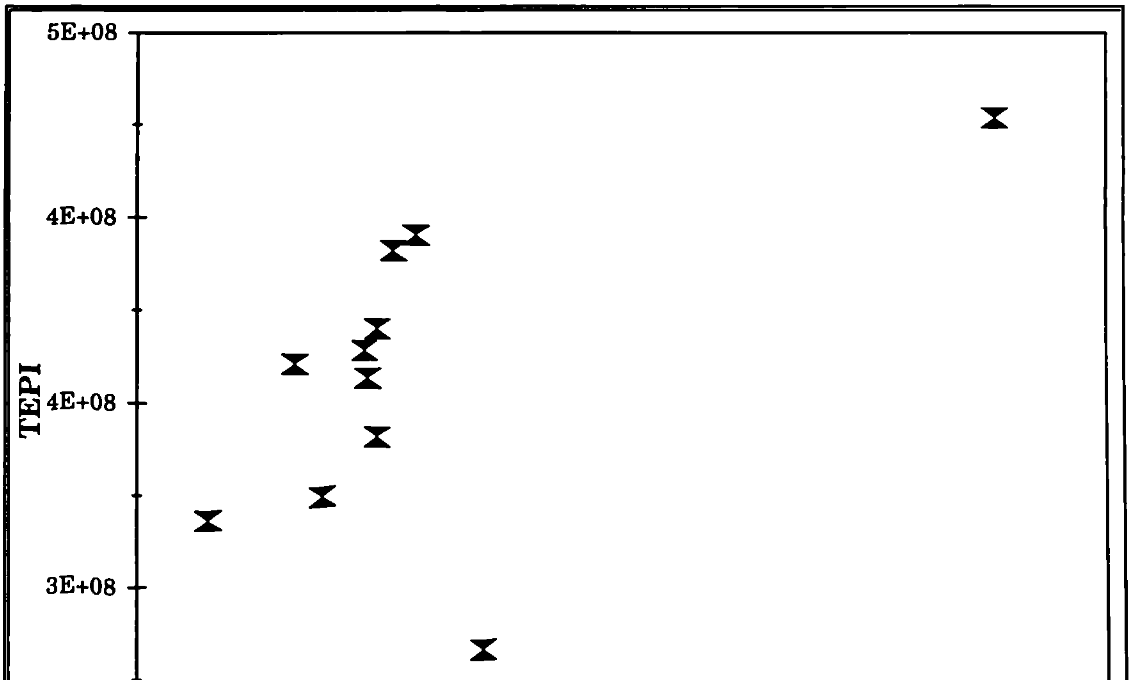


Figure 11.4 - Monthly Values of IEI against TEPI for Company B.

sulphur dioxide during period 2 (see section 4.2). Consequently, the data has a low moderate yet significant correlation coefficient of 0.6 (see Table 11.1). The rank tests for independence also suggest a positive relationship (see Table 11.2), with independence being rejected using both the TEPI and the ranked categories. The above results suggest that the IEI and TEPI might be used interchangeably, despite the large amount of potential variability visible in the plot.

Given the large amount of dispersive capacity available at the site the IEI would be expected to mirror the high capacity of the generic unit world into which the TEPI releases are modelled. However, this high capacity results in the exclusion of all water releases from the IEI as insignificant (see section 4.6). The TEPI does not exclude any emissions and variations in these may be resulting in the moderate correlation coefficient by influencing the TEPI while the IEI remains the same.

A sensitivity analysis of the IEI at Company B shows the index is dominated by emissions of sulphur dioxide. Figure 11.5 shows the percentage increase in the IEI for a 5, 10 and 50% increase in the parameters shown. The TEPI is also most sensitive to air releases, but is dominated by emissions of vanadium and carbon dioxide. The front row of Figure 11.6 shows the percentage change in the TEPI for a 50% increase in the parameters shown. The TEPI at Company B is more sensitive to emissions of vanadium and nickel as the ash generated by fuel oil combustion is not removed as in Company A.

The exclusion of carbon dioxide from the IEI may explain the moderate correlation coefficient obtained above. However, the relationship that is present between the

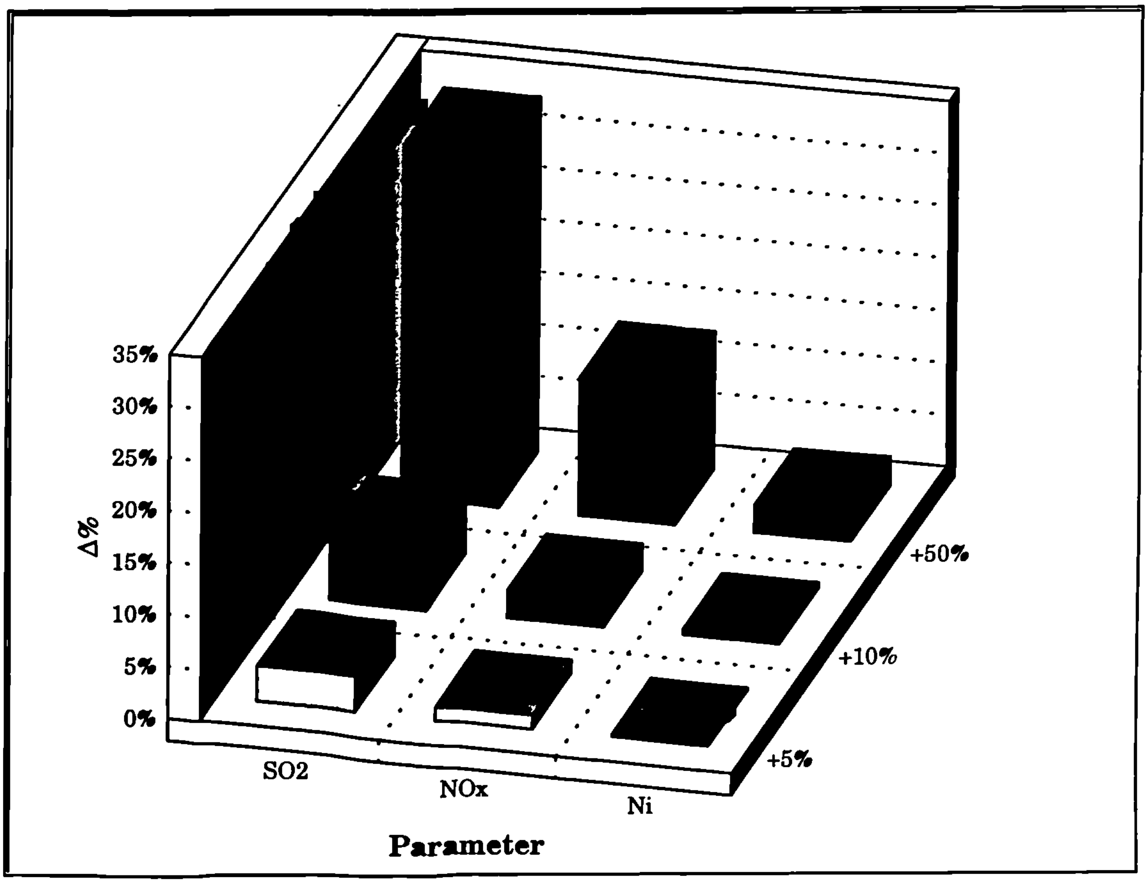


Figure 11.5 - Sensitivity of IEI to Increases in Emissions from Company B.

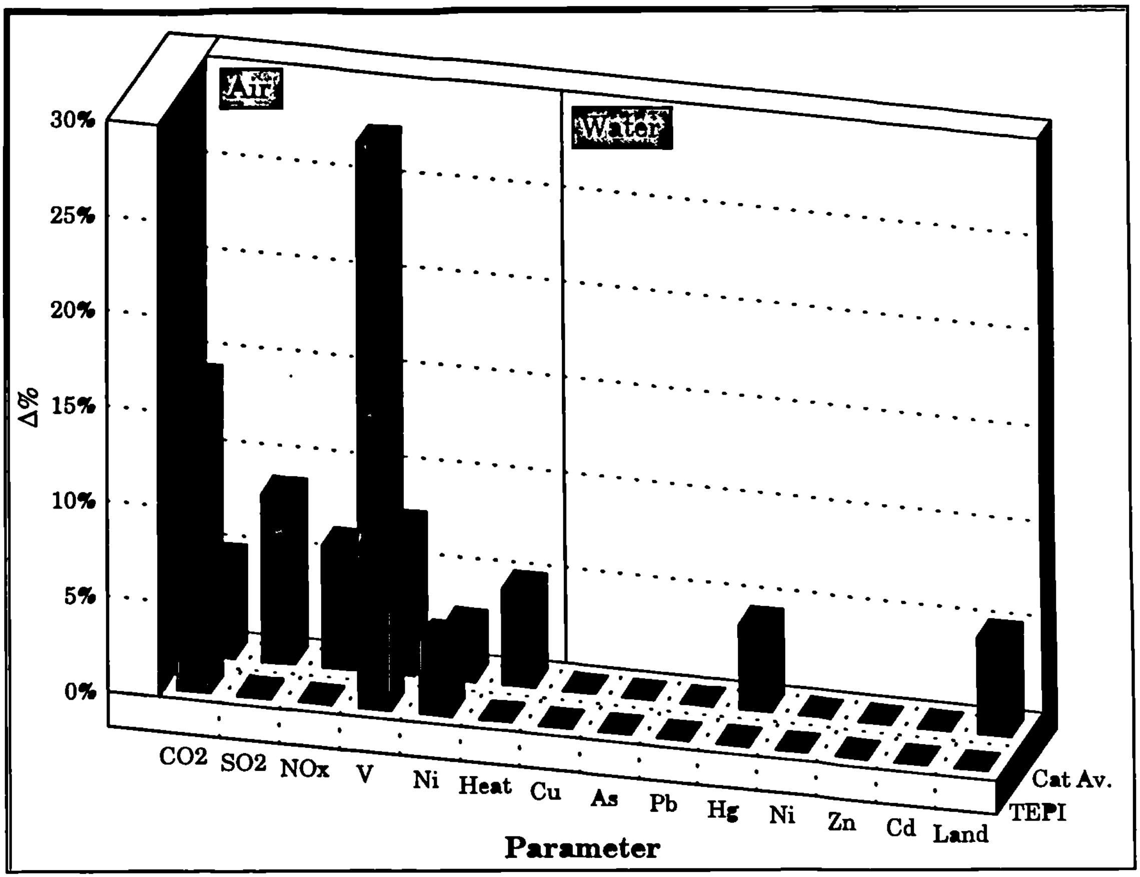


Figure 11.6 - Sensitivity of TEPI and its Categories to a 50% Increase in Emissions.

indices as they stand is not based on the release of similar substances, only on those derived from the same fuel.

The sulphur dioxide which dominates the IEI, but appears negligible in the TEPI, and the vanadium which dominates the TEPI, are all derived solely from the combustion of fuel oil. This is also the base load for the CHP plant at Company B (see section 5.2). Thus an increase in oil combustion would result in a corresponding increase in both the IEI and TEPI due to different releases. The combustion of fuel oil will also result in the release of carbon dioxide, which is not covered by the IEI. However, for fuel oil, the amount of this gas emitted should be directly related to the amount of sulphur dioxide and metals emitted, and not affect the relationship between the IEI and TEPI. As gas is also burnt at the site, the amount of carbon dioxide emitted is able to vary while sulphur dioxide and metal emissions remain the same. This also happens within the IEI, which is significantly affected by releases of NOx, which have a negligible affect on the TEPI.

The above results suggest that differences between the parameters covered by the IEI and TEPI may be affecting the relationship between them. More importantly, those that are significant in the IEI - i.e. SO_2 and NOx - do not affect the TEPI. This may be due to the additive approach taken in calculating the TEPI. As the physical relationships between the categories are presently unknown one unit of each potency category is assumed to have the same effect as another. Consequently, due to differences in the potency factors used, one category can disproportionately affect the TEPI at the expense of the other categories. For example, for 1 kg of sulphur dioxide and vanadium emitted the potency factors will be 1 and 450,000 respectively for acidification and terrestrial eco-toxicity (see section 3.4.1). The resulting category totals from the toxicity categories are, therefore, extremely high compared to those for acidification and affect the overall burden of the site more than is likely to occur in a real unit world where the interactions are known. If the average sensitivity across each of the categories is examined a different picture emerges. The back row in Figure 11.6 shows the average percentage change across the TEPI categories for a 50% increase in the parameters shown. This shows that the TEPI categories are affected by releases of vanadium, as well as sulphur dioxide and NOx and a number of other parameters previously shown as negligible. The category average shows a more balanced result, given the known burdens from Company B. As the site is subject to the Large Combustion Plant Directive, its sulphur dioxide and NOx emissions must be significant. The higher test statistic, $T_R^\#$, suggests that this significance would be recognised when using the TEPI categories rather than the TEPI itself (see Table 11.2).

At Company B the interchangeability of the IEI and TEPI, although feasible, appears to be affected by both the exclusion of global parameters from the IEI, and the disproportionate effect of categories within the TEPI. This would not have been expected at a site with a high environmental capacity, which should be similar to the unit world modelled in the TEPI. As a result, where different fuel or process mixes are being assessed the comparability of the IEI and TEPI cannot be guaranteed.

The potential use of the TEPI as a non-parametric process ranking tool is also affected by the above results. The ranked IEI and TEPI values give a moderate significant correlation coefficient of 0.6. However, in line with the results obtained above, this increases to 0.8 when the ranked TEPI categories are used. This suggests that there may be a role for using the TEPI categories as a process ranking tool, based on the processes present at Company B.

Company C.

The plot of monthly values for the IEI and TEPI at Company C suggest a linear relationship as shown by the plot in Figure 11.7. The data has a significant high correlation coefficient of 0.9 and the rank test for independence also suggests a positive relationship (see Table 11.2), rejecting independence for both the TEPI and its ranked categories. However if the BOD parameter is included in the IEI, the relationship between the indices weakens, with the data points becoming more widely distributed.

Given that this parameter is included in the TEPI as COD, a stronger relationship would have been expected where similar environmental burdens are included. The comparative results obtained including BOD are shown in Figure 11.8. The correlation coefficient for the data falls to 0.6 but remains significant (see Table 11.1), reducing the potential for using the indices interchangeably. The reduction in linearity does not affect the rank tests significantly enough to accept independence using either the TEPI or the ranked categories (see Table 11.2). The above data suggests that the two indices can be used interchangeably, but that the basis for this is weaker when the BOD parameter is included in the IEI. This suggests that the strong relationship present without BOD may be due to other parameters.

A sensitivity analysis of the IEI for Company C shows the index is dominated by air emissions of sulphur dioxide and NOx, followed by particulates to air and iron

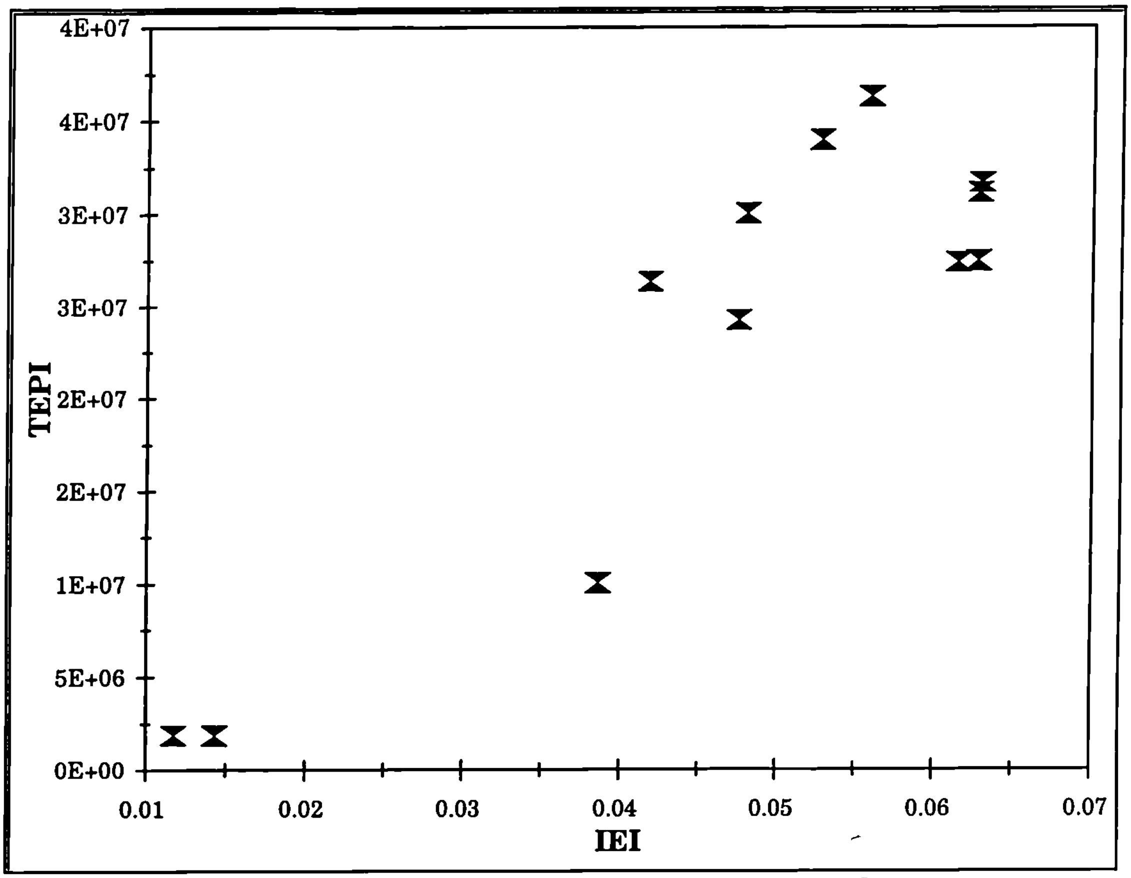


Figure 11.7 - Monthly Values of IEI against TEP for Company C.

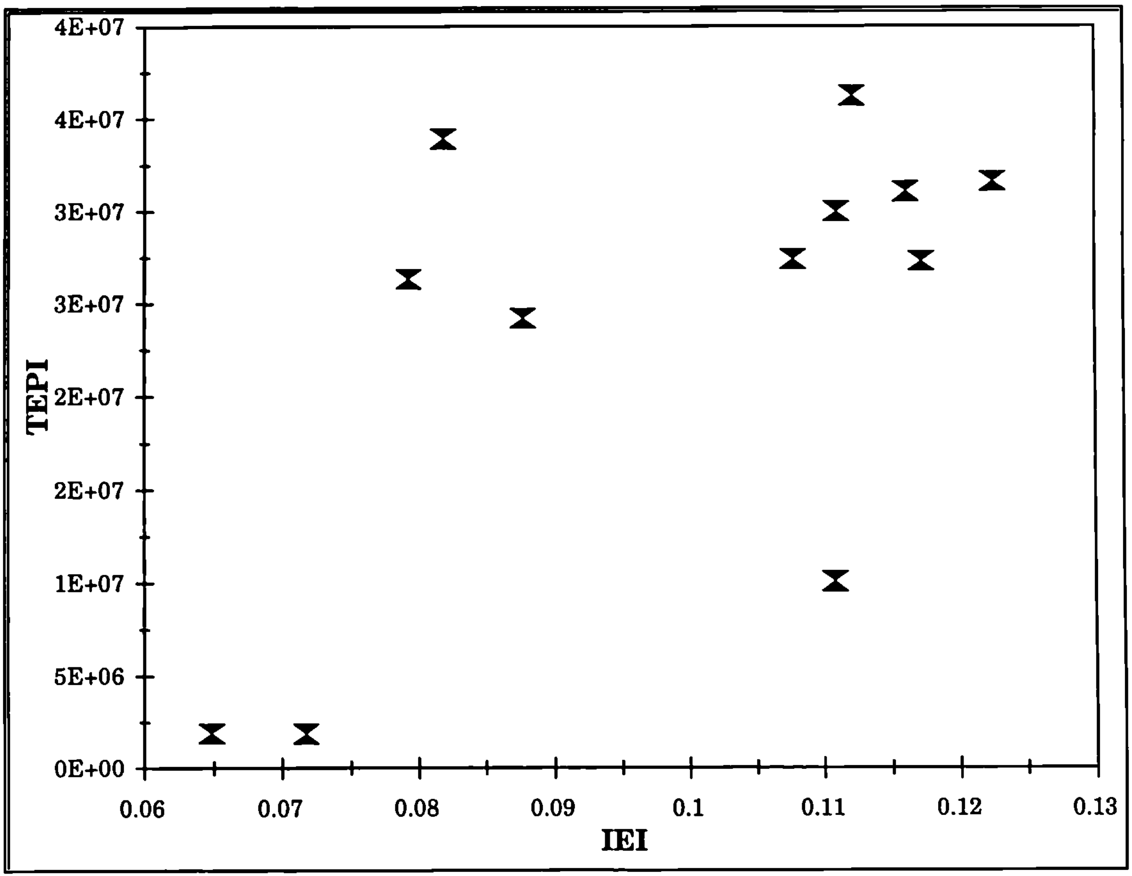


Figure 11.8 - Monthly Values of IEI against TEPI (BOD in IEI) for Company C.

to water. Figure 11.9 shows the sensitivity of the IEI to increases in the parameters covered for Company C. The TEPI is also dominated by releases to air, but is most sensitive to emissions of vanadium, followed by carbon dioxide and nickel. The front row in Figure 11.11 shows the results for a 50% increase in the parameters shown.

When BOD is excluded from the IEI the two indices are most sensitive to releases derived from a similar source or process within the company. The sulphur dioxide and vanadium emitted are both derived from the combustion of fuel oil at the site. The company also uses natural gas, which does not affect the indices in a similar way. This might explain the moderate correlation coefficient obtained, with the exclusion of carbon dioxide from the IEI also contributing to this. However, when BOD is included in the IEI its drivers change (see Figure 11.10), with BOD and sulphur dioxide emissions dominating the index. This suggests that when the TEPI needs to take account of a number of different process related emissions it is not able to aggregate these in a similar way to the IEI. This is likely to be due to the additive approach used in the TEPI, rather than site constraints on the company.

If the sensitivity of the TEPI categories is studied this shows a more appropriate mix of drivers for the site, although the contribution made by COD to the total is still very small. The second row of Figure 11.11 shows the average change across the categories for a 50% increase in the parameters. Given the above results this suggests that the TEPI is not very good at quantifying the burden from emissions to water, and that the basis for the strong relationship present for the first data set is not valid. The indices should not be used interchangeably at this site, therefore.

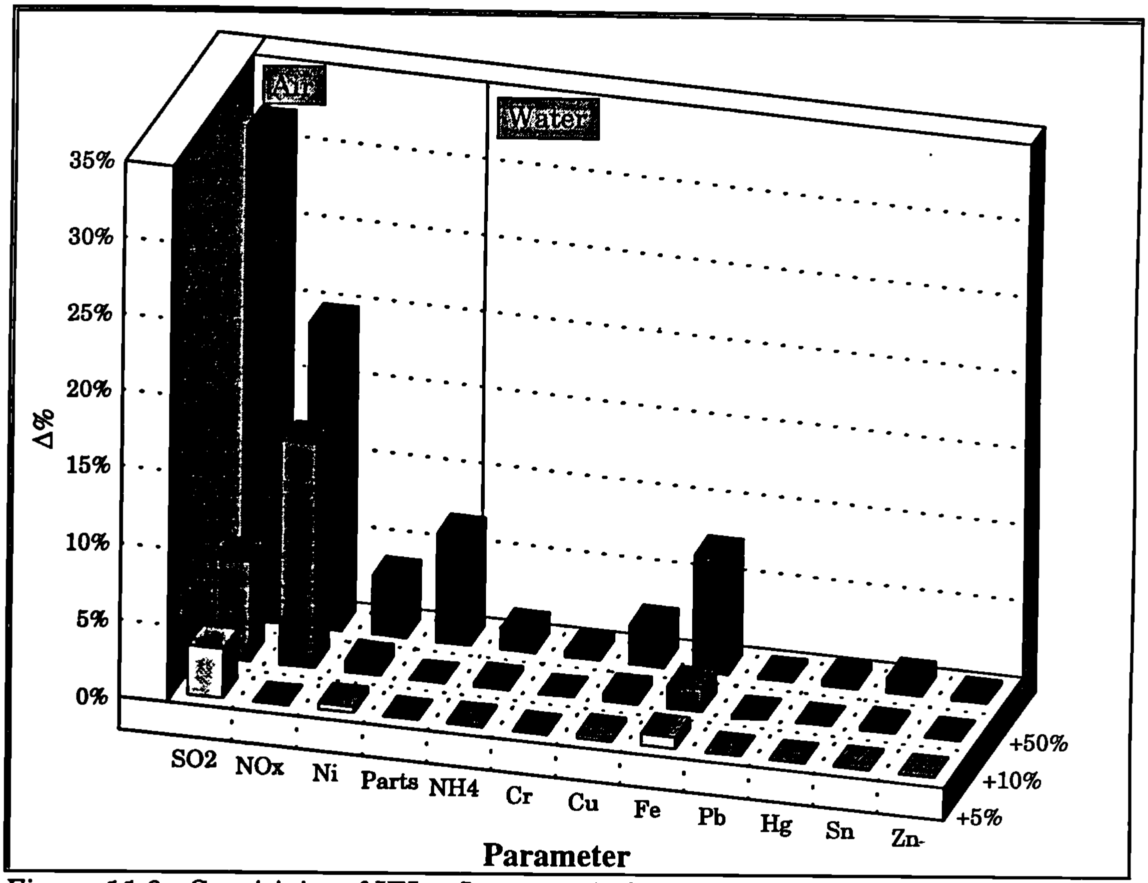


Figure 11.9 - Sensitivity of IEI to Increases in Emissions from Company C.

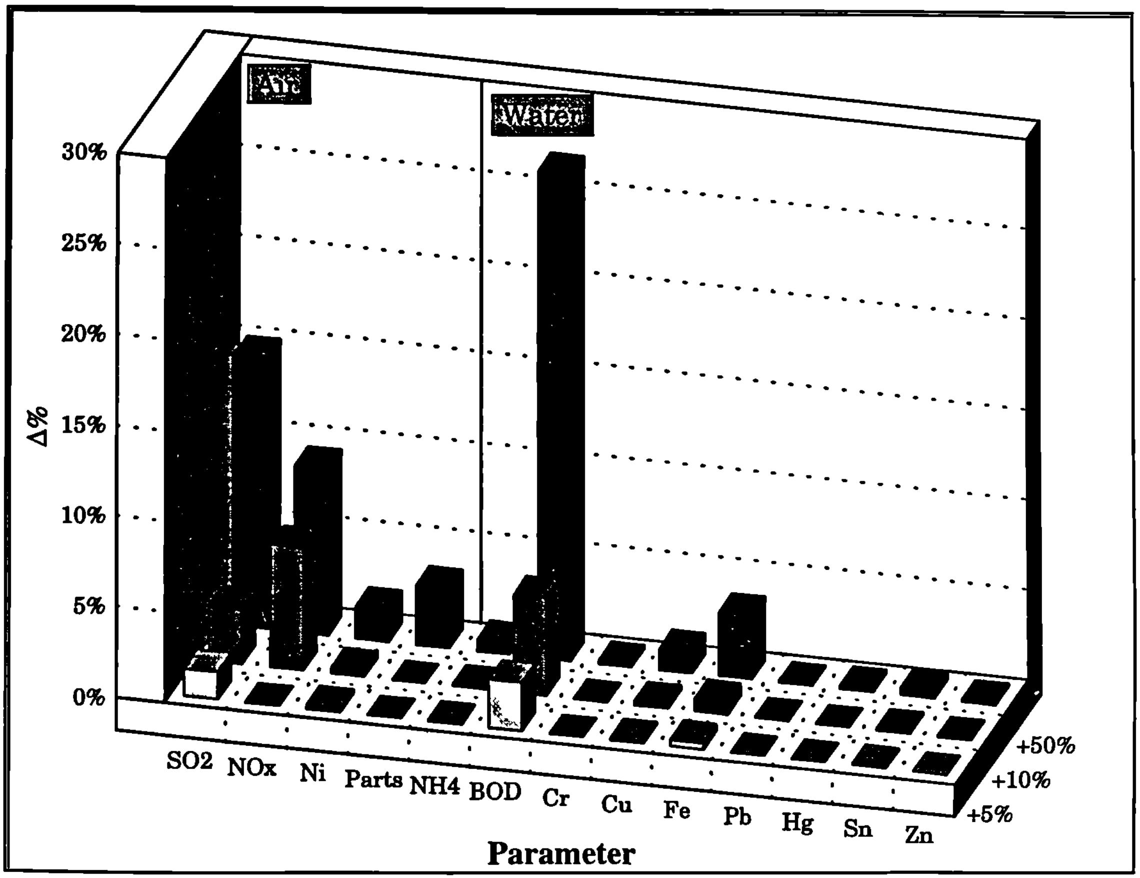


Figure 11.10 - Sensitivity of IEI to Increases in Emissions, with BOD.

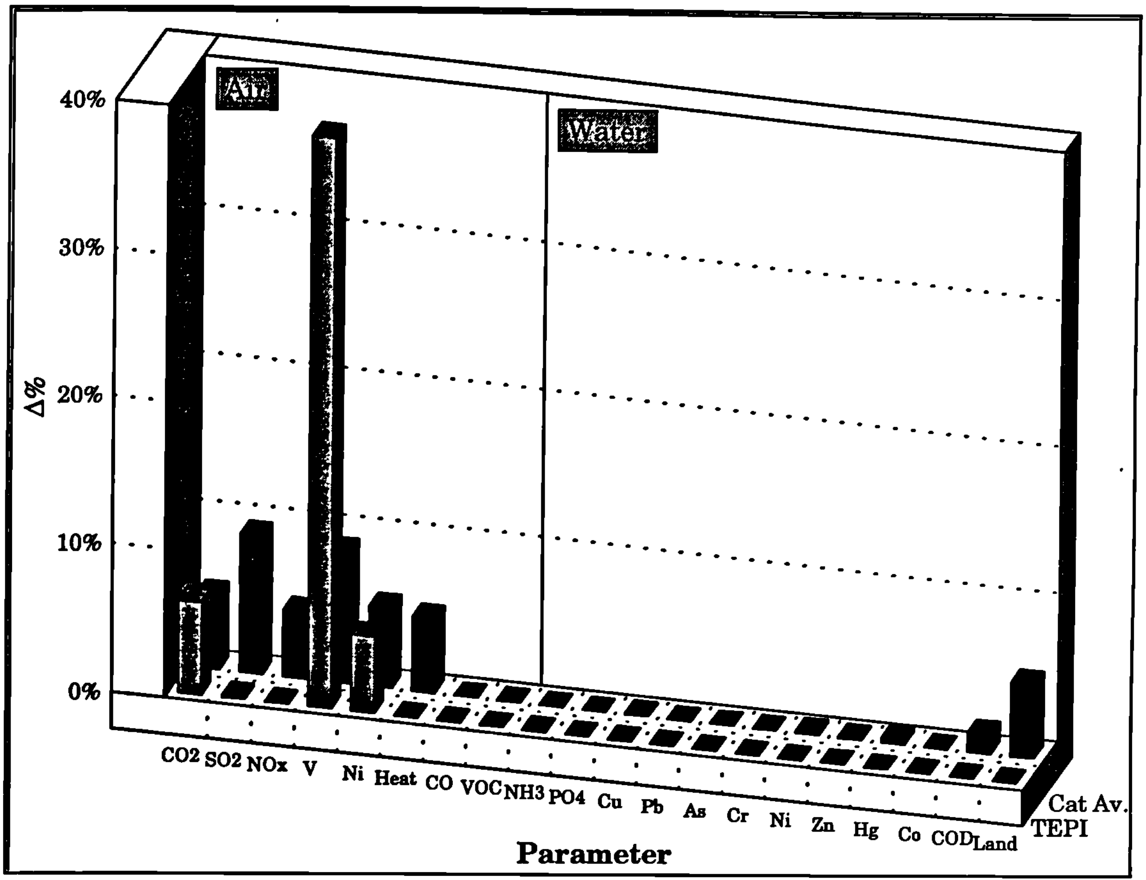


Figure 11.11 - Sensitivity of TEPI and Categories to a 50% Increase in Emissions.

The potential use of the TEPI as a non-parametric process ranking tool is affected less by the BOD parameter than the results above. The ranked IEI and TEPI values give a high correlation coefficient of 0.8 and 0.6 without and with the BOD parameter respectively. These values are little affected by the use of the ranked categories (see Table 11.3). This suggests a limited role for the TEPI where releases to water are to be included.

In contrast to the previous two companies the use of the ranked categories actually causes a reduction in the test statistics for the rank tests in Table 11.3.

Company D.

At Company D the monthly IEI and TEPI values show no clear relationship (see Figure 11.12). The correlation coefficient is insignificant (r = 0.5) and is influenced strongly by the low outlier at the bottom of the graph (see Table 11.1). This corresponds to low BOD emissions during period 6 (see section 7.2). The rank test for independence gives similar results, accepting the null hypothesis when both the TEPI and its ranked categories are used (see Table 11.2). In the previous company comparison the inclusion of BOD into the IEI also caused problems with the TEPI. At this site, however, this is also due to the limitations within the surface water to which the BOD is discharged. Both these factors may be affecting the relationships between the two indices.

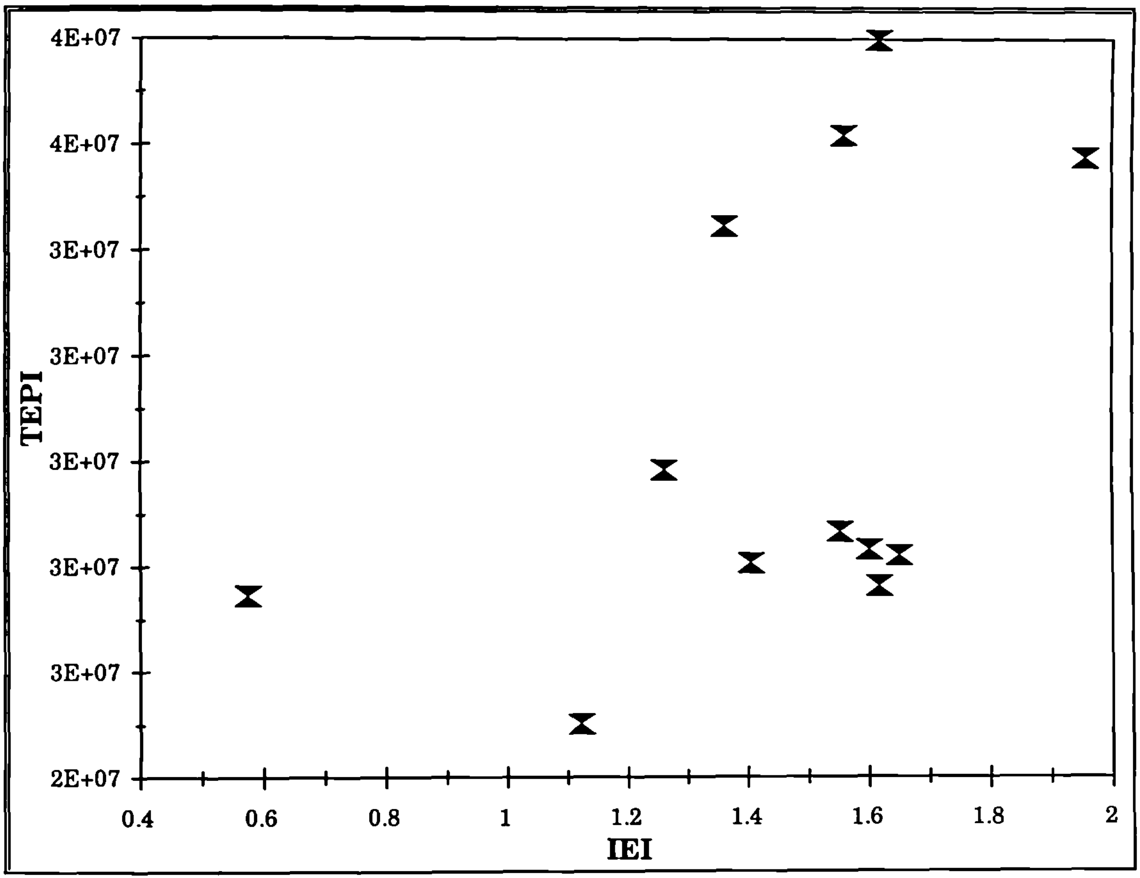


Figure 11.12 - Monthly Values of IEI against TEPI for Company D.

The sensitivity analysis of the IEI for Company D shows the index is dominated by releases of BOD and copper to water, with limited sensitivity to air releases. Figure 11.13 shows the sensitivity of the IEI to changes in the parameters covered. The TEPI, in contrast, is dominated by releases to air. These are shown in the front row of Figure 11.14 for a 50% increase in the parameters. The TEPI, which is affected by twice as many parameters for Company D, is dominated by releases of chromium, followed by carbon dioxide, vanadium, nickel and copper. All these releases are derived from the combustion of coal on the site.

These differences help explain the independence of the IEI and TEPI. With limited river flow compared to the other companies (see Chapters 4 to 10) the IEI is dominated entirely by releases to water. Were this not the case, as at the previous paper manufacturer, a more balanced sensitivity to air and water releases would be expected. Despite these restrictions the quantity of BOD released from the site is still large, but is seen as negligible by the TEPI. As for previous companies the TEPI is dominated by carbon dioxide and metals emissions to air, whereas the limited sensitivity in the IEI centres on sulphur dioxide and NOx emissions. This suggests that both site location and the TEPI's additive approach appear to be affecting the comparative results obtained.

The particular sensitivity of the IEI to water releases at this site becomes evident when the sensitivity results are compared to those obtained using the TEPI categories. These give a more balanced view of the importance of the parameters released to air, with sulphur dioxide and NOx also showing significant change. The second row in Figure 11.14 shows the average change across the categories for a 50% increase in the parameters covered. The results also show that as the COD parameter only contributes to one category it has a limited effect with the present set-up of the generic index. This seems to support the weaknesses observed at previous companies for assessing releases to water as part of the TEPI.

The above results have shown that the exclusion of global factors from the IEI and

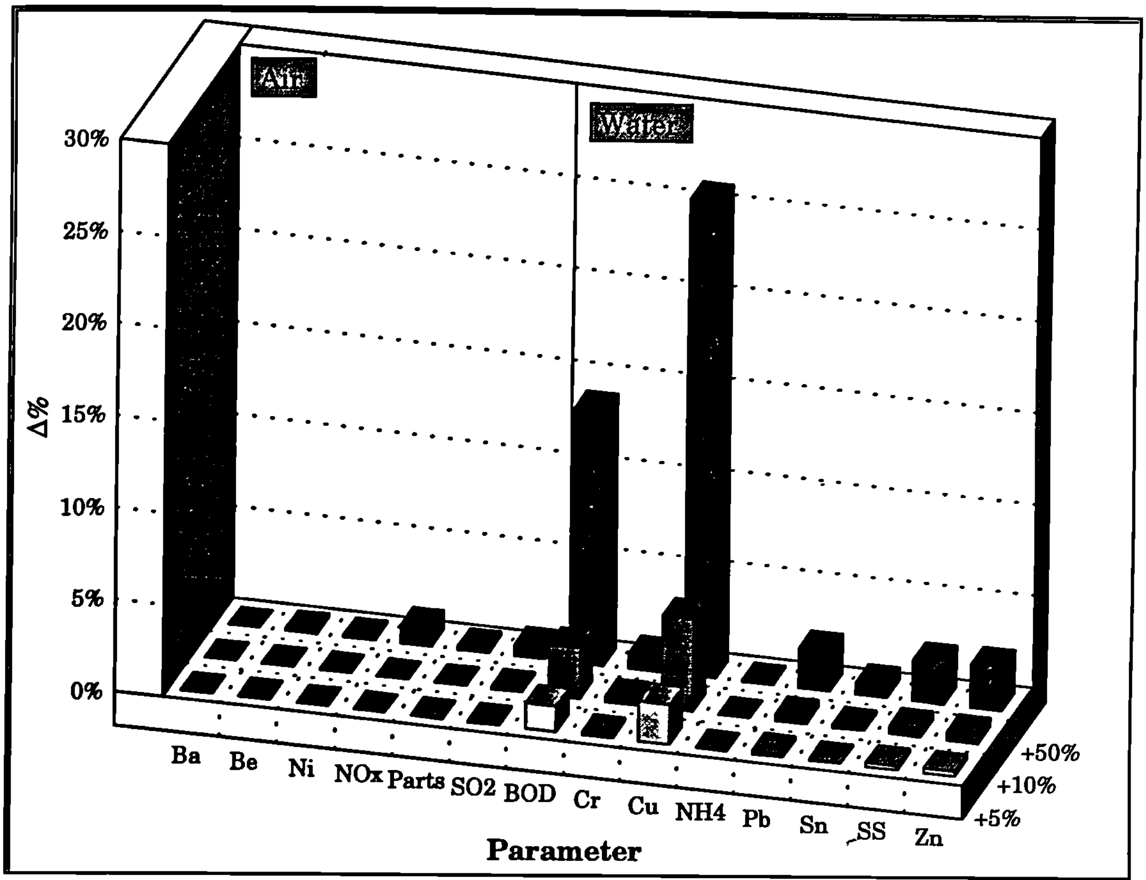


Figure 11.13 - Sensitivity of IEI to Increases in Emissions from Company D.

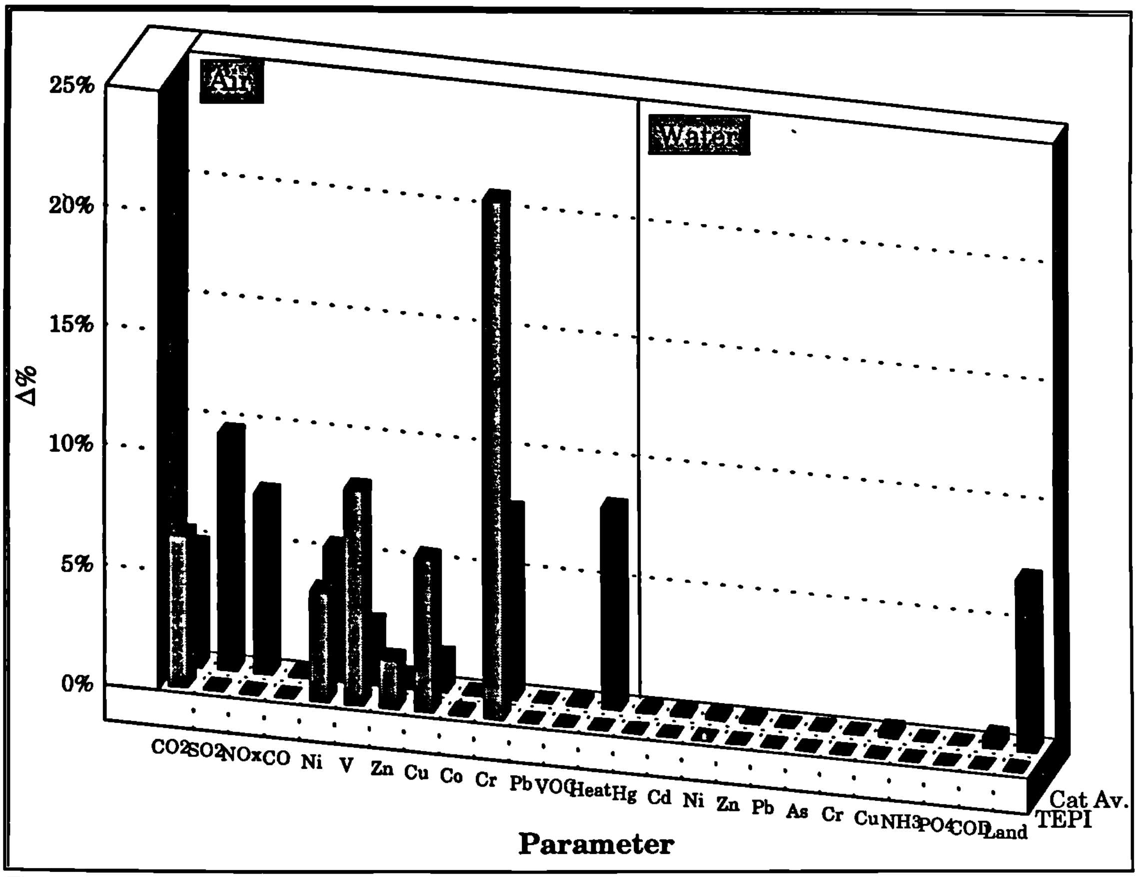


Figure 11.14 - Sensitivity of TEPI and Categories to a 50% Increase in Emissions.

the additive approach used in the TEPI are again affecting the relationship between the IEI and TEPI. However, in this case the site-specific limitation at Company D has shown that this can significantly affect the IEI results obtained. As a result the IEI and TEPI cannot be used interchangeably at this site.

The potential use of TEPI as a process option ranking tool is also limited at Company D. The coefficient of variation between the indices is insignificant for both the TEPI and its ranked categories (see Table 11.3). This combined with the acceptance of independence by the rank test suggests that the two are completely independent at this site and the TEPI could not be used as a site application tool.

Company E.

Company E was only able to provide quarterly data for the project, which is only just representative at a site level. The four data points shown in Figure 11.15 suggest a strong linear relationship and results in a high correlation coefficient of 0.9, which is just significant (see Table 11.1).

This is counteracted by the rank test for independence which accepts the null hypothesis for both the TEPI and its ranked categories. This suggests that the two indices cannot be used interchangeably at Company E and that the scale of the two indices may be affecting the results obtained.

A sensitivity analysis of the IEI shows the index is most sensitive to air releases, as shown in Figure 11.16. The IEI is dominated by releases of NOx from gas combustion, and chlorine and xylene gas released via the process vents at the site.

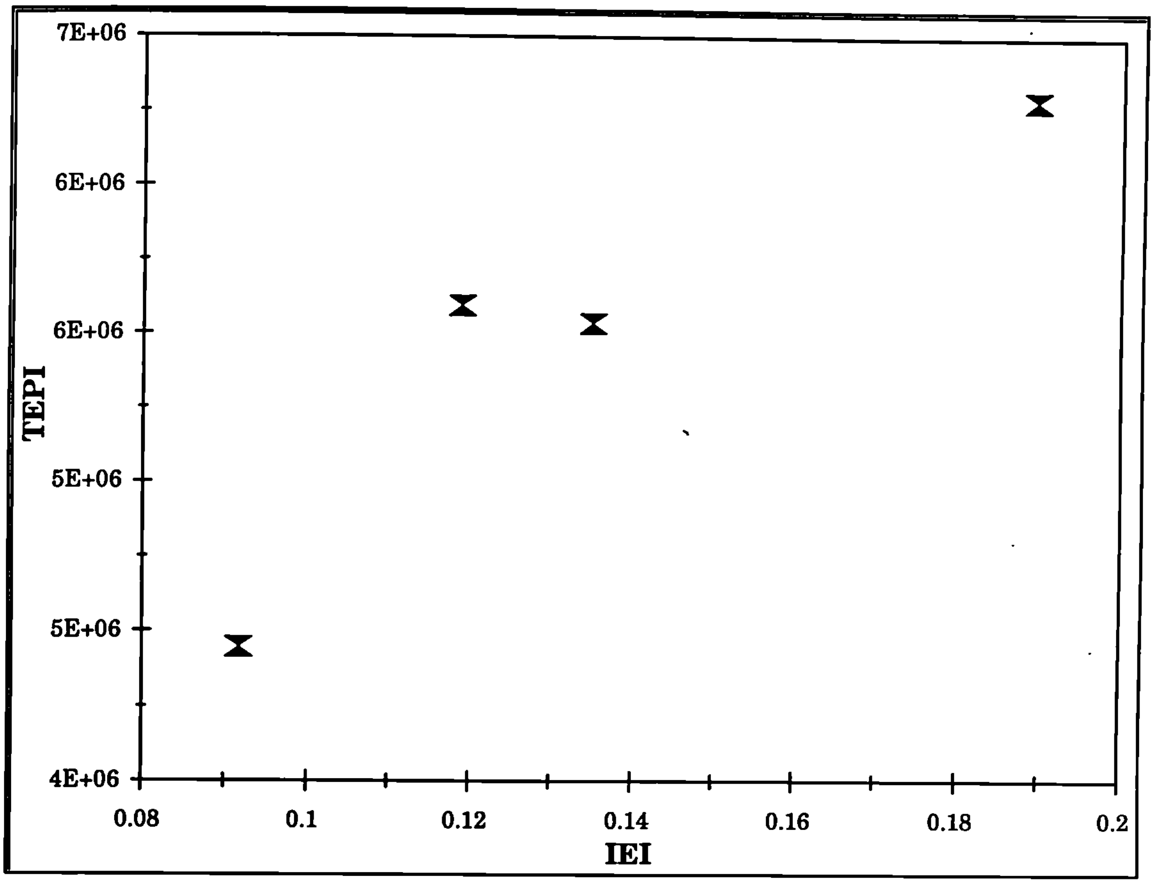


Figure 11.15 - Monthly Values of IEI against TEPI for Company E.

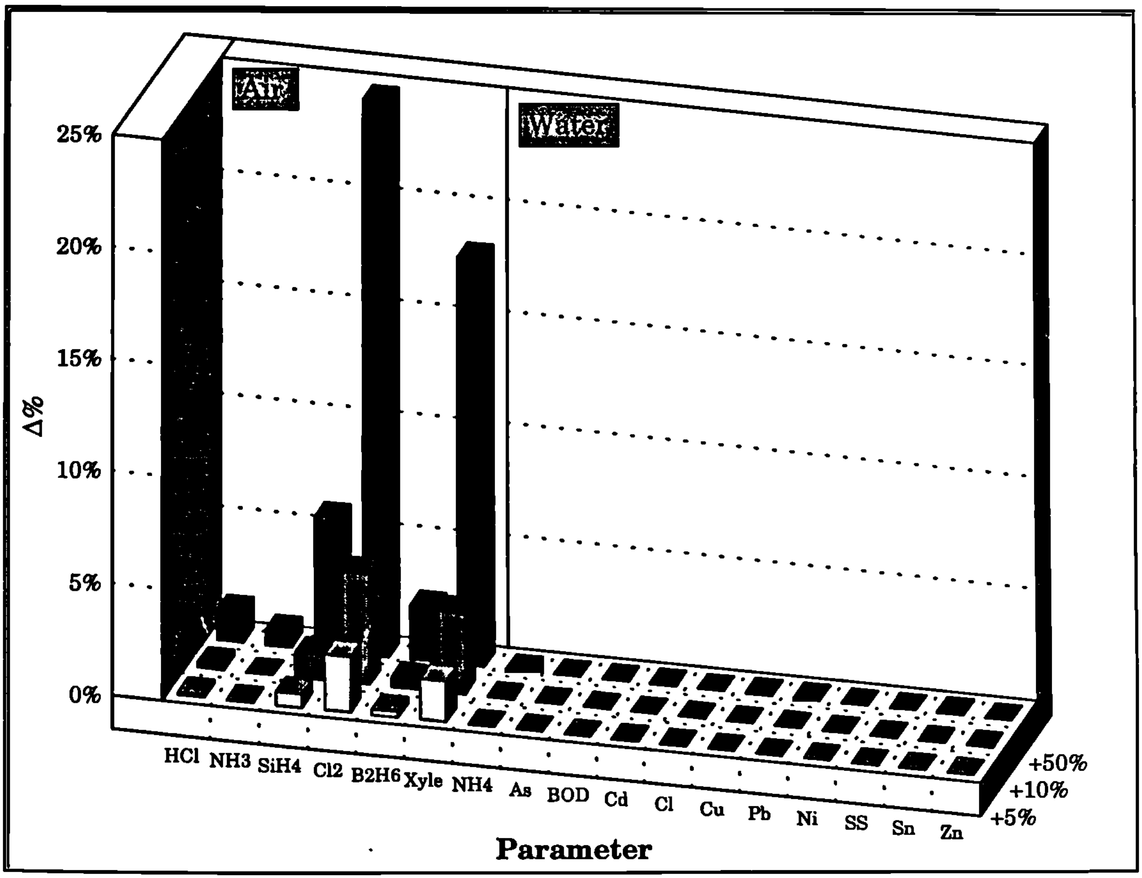


Figure 11.16 - Sensitivity of IEI to Increases in Emissions from Company E.

The TEPI, which covers five additional parameters, is also dominated by releases to air. The front row in Figure 11.17 shows the percentage change in the TEPI for a 50% in the parameters given. The TEPI is dominated primarily by the global warming gases carbon dioxide, nitrous oxide and carbon tetrafluoride, none of which are covered by the IEI. The connection between these rele21ases and those affecting the IEI are less clear than at the other sites, as the black box from which they were released contains a wide range of processes. Both carbon dioxide and NOx are released primarily from the combustion of natural gas at the site.

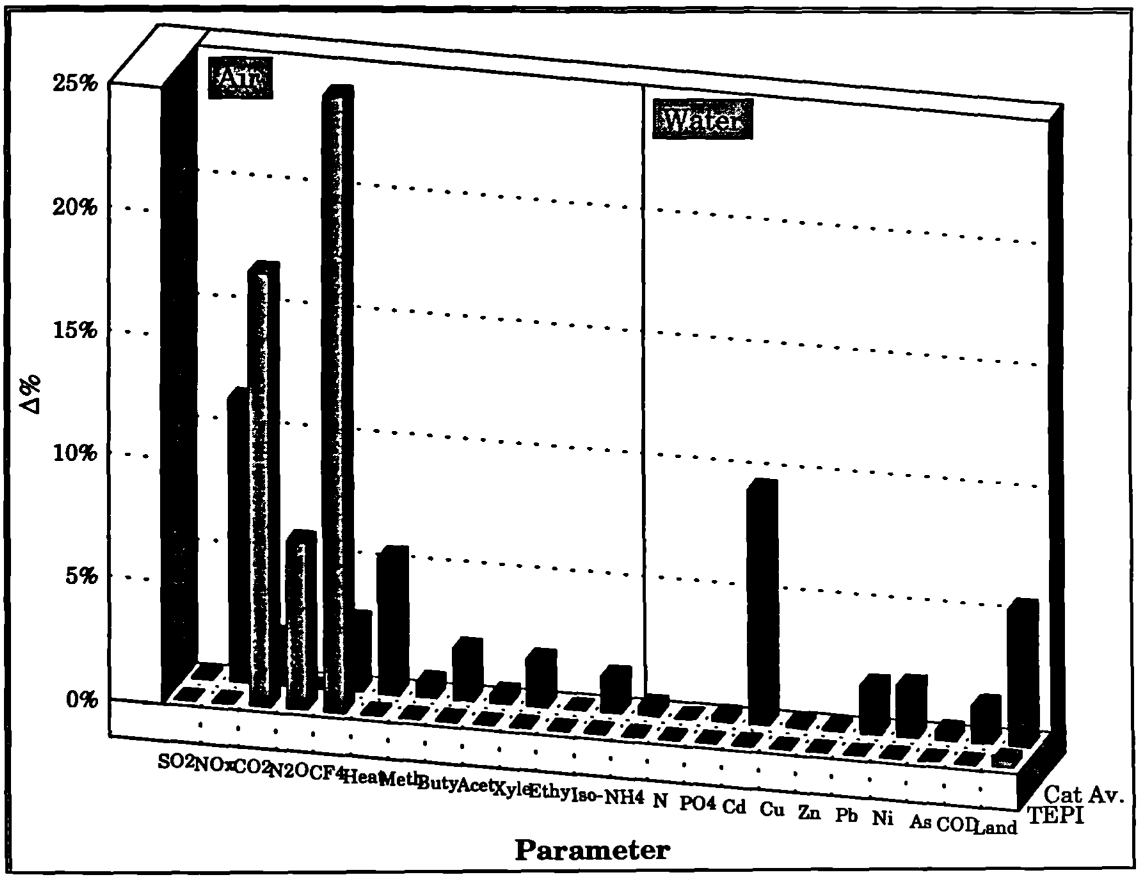


Figure 11.17 - Sensitivity of TEPI and Categories to a 50% Increase in Emissions.

However, neither of them dominate the two indices enough to suggest a connection. It is unclear whether the other releases originate from a similar process within the site. The stack data in Table 8.10 does show that nitrous oxide, carbon tetrafluoride and chlorine are all released via the same stacks. This might indicate releases from the same process and explain the high correlation coefficient value obtained for the data. This is not true for xylene, however. As at the previous site the indices appear to be influenced by different parameters which may be linked to a similar process. The low number of data points available, however, has made an assessment of the true relationship present difficult. The IEI presently excludes the global warming gases, which dominate the TEPI. The high category totals obtained by the greenhouse effect category do not appear to have affected the acceptance of independence between the two indices at this site, even using the ranked categories (see Table 11.2). The sensitivity of these categories, as shown in the back row of Figure 11.17, gives a more balanced picture, with NOx and xylene also showing up as moderately sensitive.

The above data suggests that given the indices cannot be used interchangeably at Company E. *The two indices respond to very different parameters which* may or may not be linked to a similar process. As seen in some of the previous companies, a range of processes can cause problems for the TEPI, together with fuel mix or other emissions changes. These problems may account for the acceptance of independence by the rank tests.

The potential use of the TEPI as a non-parametric process ranking tool is unclear. The high significant correlation coefficient obtained when using the TEPI is reversed when the ranked categories are used. This reflects the independent results obtained from the rank tests above.

Due to a lack of data and widely disparate sensitivities within the indices the TEPI should not be used as a site application tool.

Company F.

The IEI for company F was zero for each of the monthly assessment periods, which has not allowed a quantitative comparison to be made between the indices. It has been assumed, as the IEI remains zero while the TEPI values vary, that the null hypothesis for independence has been accepted.

A sensitivity analysis of the TEPI, for a 50% increase in the parameters (see Figure 11.18), shows the index is dominated by carbon dioxide releases from the gas burnt at the site. The TEPI is also dominated by the greenhouse effect category, with the category average showing a more balanced picture for the site.

The IEI and TEPI values calculated for this site will be included in the overall assessment in section 11.2.2.

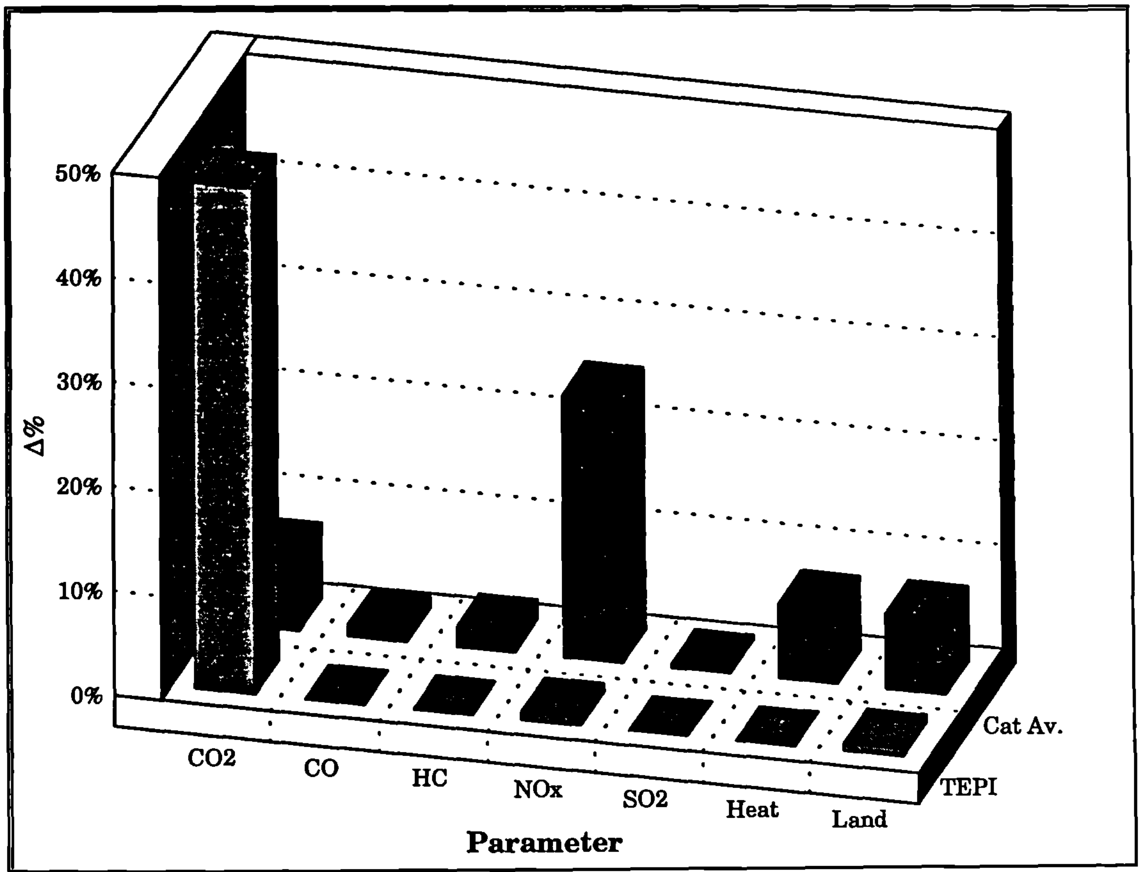


Figure 11.18 - Sensitivity of TEPI and Categories to a 50% Increase in Emissions.

Company G.

Comparison of the monthly IEI and TEPI values at Company G suggests a linear relationship, with a high correlation coefficient of 0.9 (see Table 11.1), strongly influenced by a high outlier at the top of the graph (see Figure 11.19). This represents a high emission of vanadium in period 12, which affects the TEPI but not the IEI. The significant correlation coefficient suggests that the two indices might be used interchangeably.

However this is counteracted by the rejection of independence using the rank tests for the TEPI and its ranked categories (see Table 11.2). This suggests that the scale of the two indices may be affecting the results obtained. These presently exclude the BOD parameter from the IEI as Company G is situated along an estuary. Including BOD into the IEI, as it is the primary environmental burden to water from the site, changes the results obtained. Figure 11.20 shows a more even distribution of data points, which results in a significant correlation coefficient of 0.8. Similarly to Company C, the correlation coefficient actually falls when BOD is included, suggesting that other parameters are causing the strong relationship present where BOD is excluded from the IEI. The ranks tests are similarly affected by the BOD parameter, with both rejecting the independence of the two indices less strongly(see Table 11.2).

A sensitivity analysis of the IEI excluding BOD shows the index is dominated by releases to air. Figure 11.21 shows the percentage change in the IEI for a 5, 10 and 50% increase in the parameters covered. The IEI is most sensitive to sulphur dioxide, followed by NOx and nickel. The TEPI is also dominated by releases to air, but by different parameters.

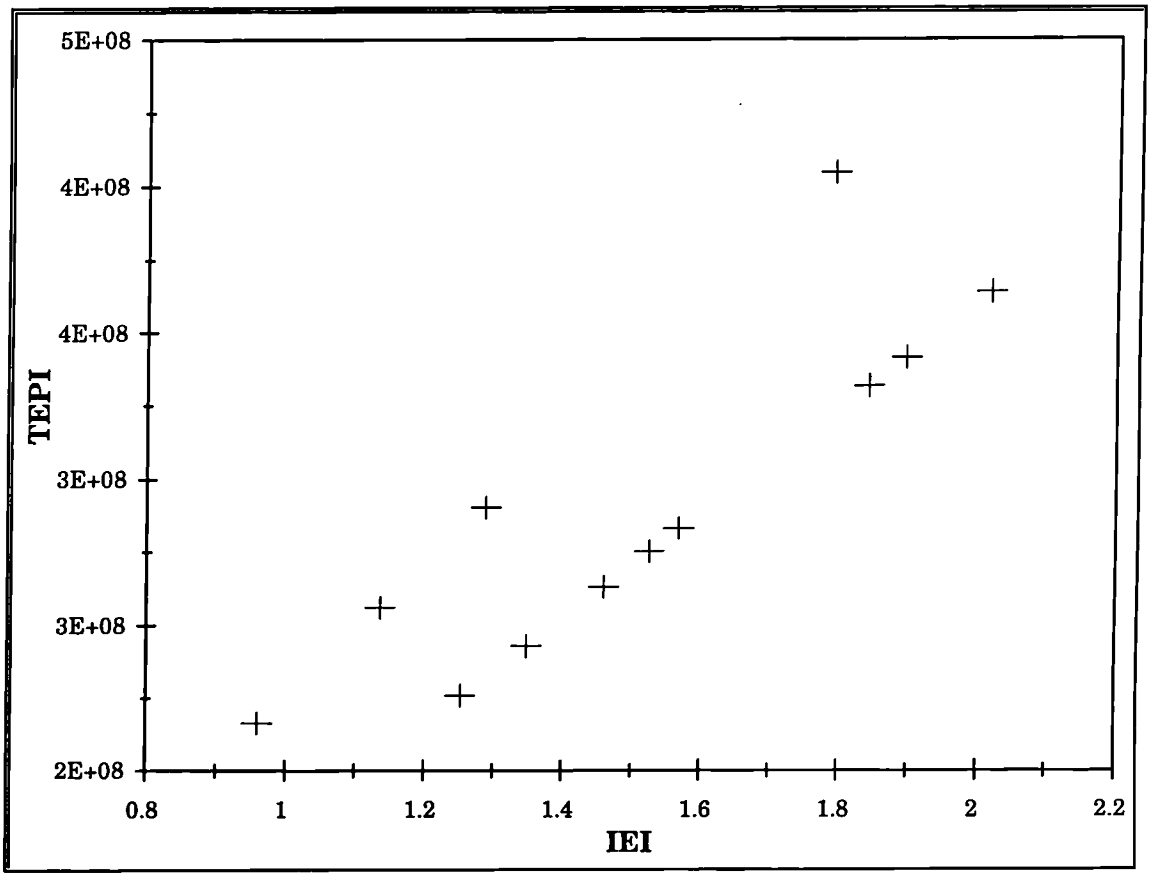


Figure 11.19 - Monthly Values of IEI against TEPI for Company G.

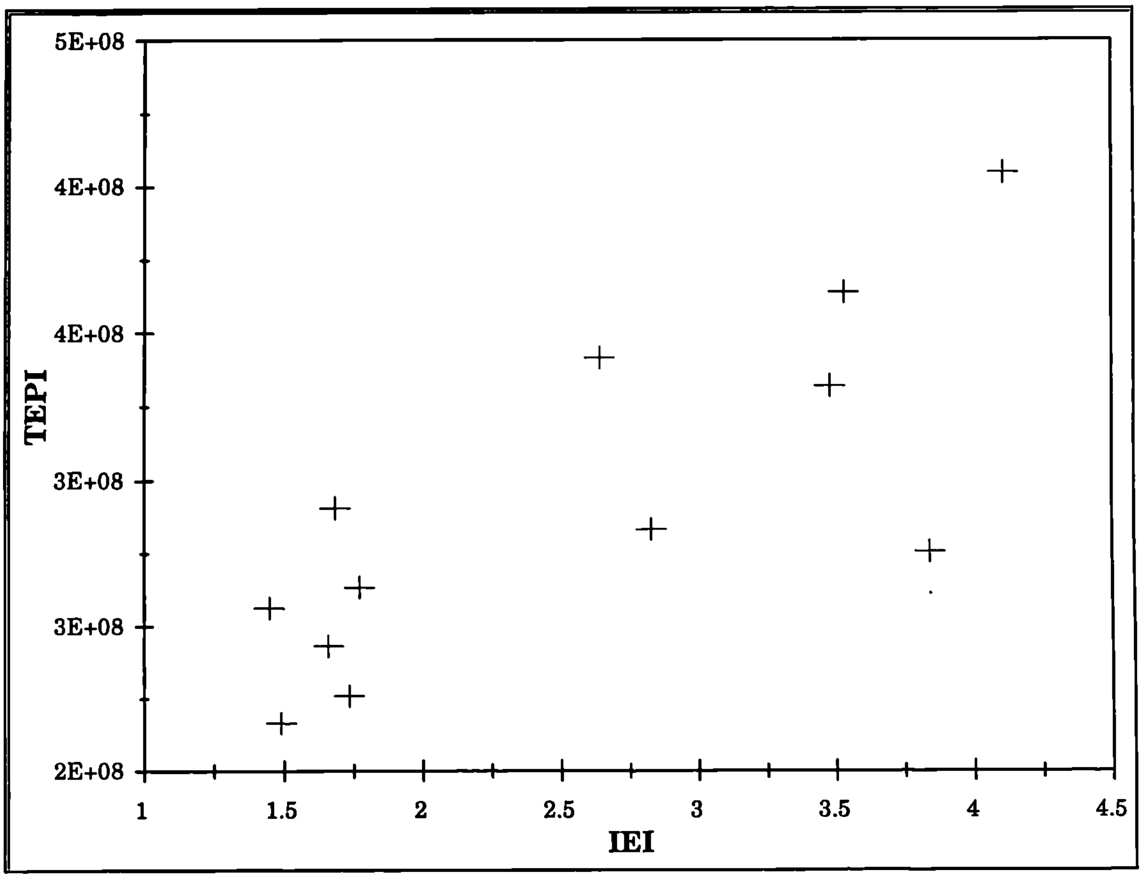


Figure 11.20 - Monthly Values of IEI against TEPI (BOD in IEI) for Company G.

Figure 11.23 shows the percentage change in the TEPI for a 50% increase in the parameters given. The TEPI, which is affected by over four times as many parameters as the IEI at this site, is dominated by releases of vanadium, followed by carbon dioxide, vanadium and nickel. The metals contribute to the toxicity categories which over-ride the index. Despite the large number of parameters which affect the TEPI, but not the IEI, a high correlation coefficient has still been achieved.

All the emissions mentioned above are derived from the combustion of fuel oil at the site, which is its only fuel source. As a result an increase in one index results in an almost identical relative increase in the other. The emissions to water of BOD are represented in the TEPI as COD, but appear to have very little effect on the TEPI total. This is because COD only affects one category, but the potency factors used within the category are also low per unit of material emitted, compared to those in the toxicity categories. When BOD is included in the IEI, the sensitivity of the index changes, being shared equally between the BOD and sulphur dioxide, thus removing the process related connection between the indices (see Figure 11.22). Consequently, the TEPI appears to have problems dealing with multiple process emissions, especially to water. The effect of including BOD is less significant here, than it was at Company C, as more capacity is available to absorb the large quantities of BOD released. The IEI is therefore less affected.

A sensitivity analysis of the category average for the site shows a more balanced response to the known burdens from the site, with sulphur dioxide and NOx having a significant effect together with carbon dioxide, vanadium and nickel (see Figure 11.23). However, the TEPI still fails to pick up on the high COD emissions to water.

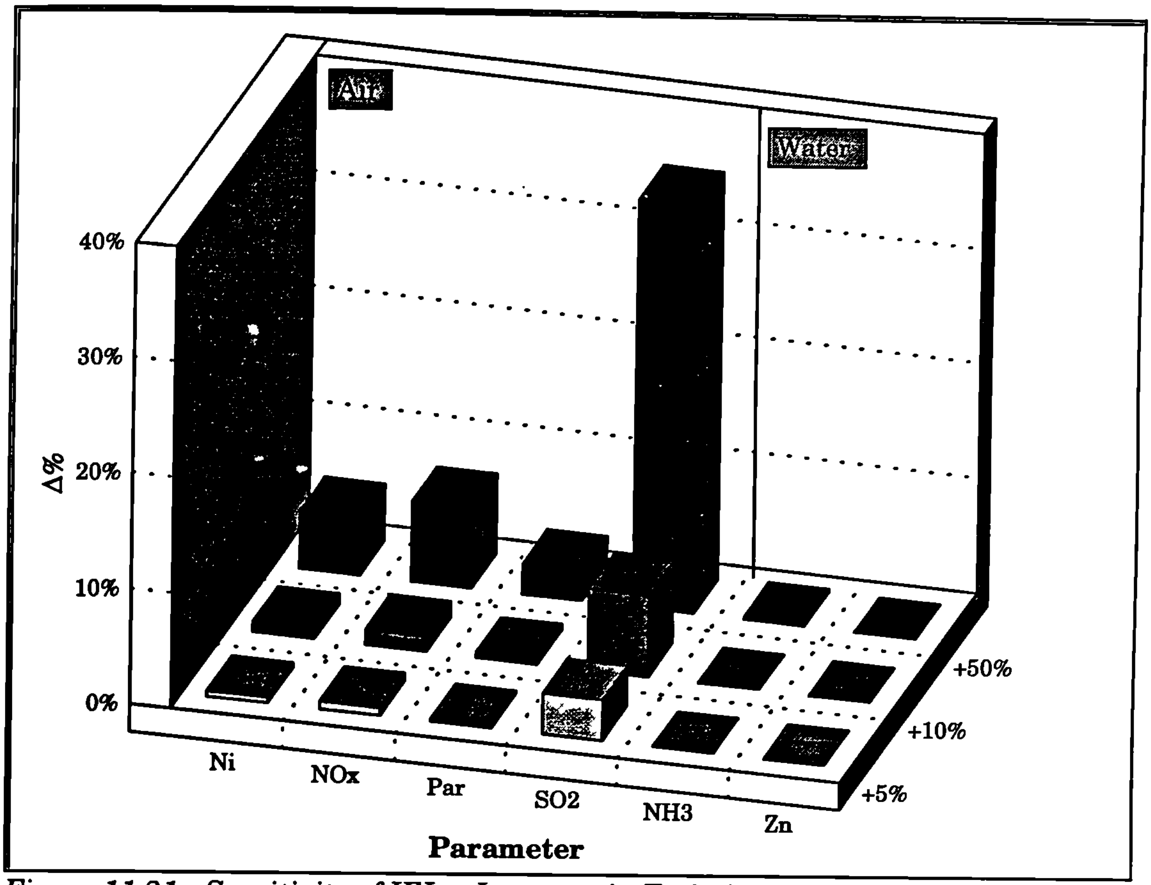


Figure 11.21 - Sensitivity of IEI to Increases in Emissions from Company G.

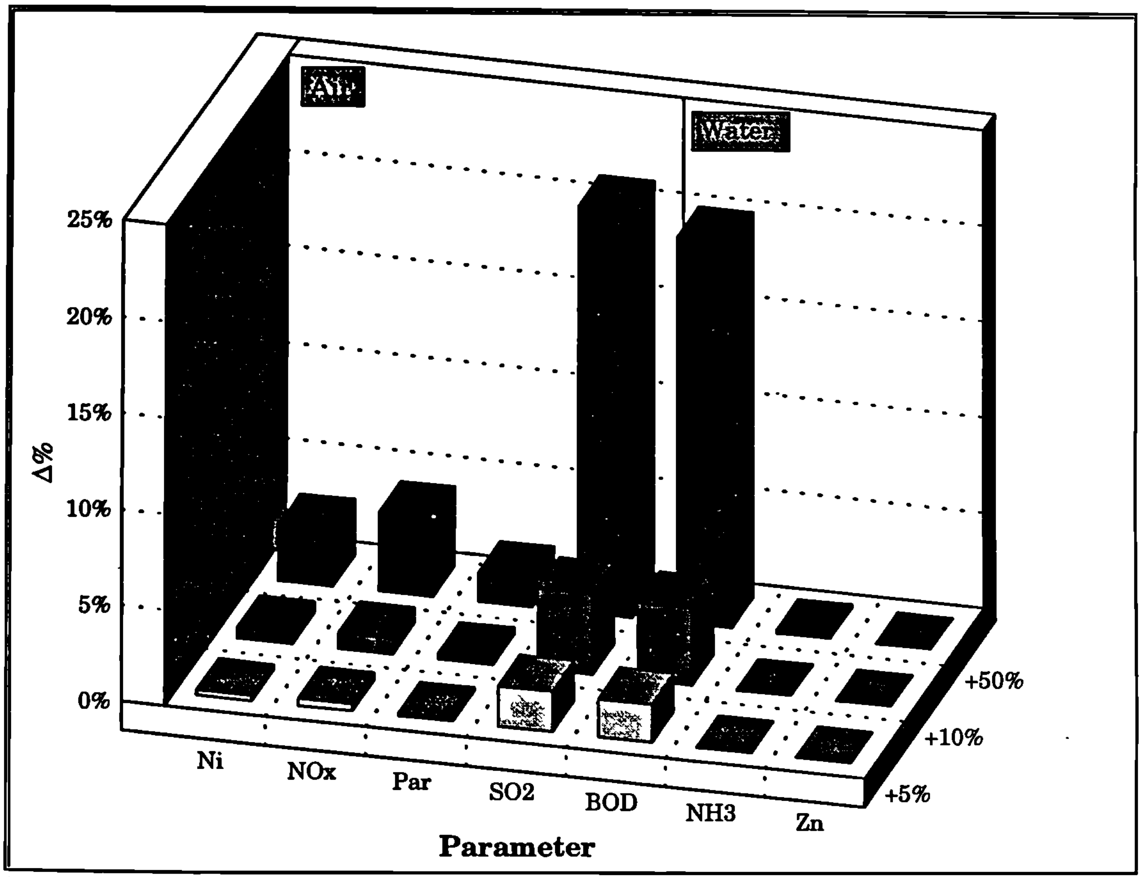


Figure 11.22 - Sensitivity of IEI to Increases in Emissions, with BOD.

The above data suggests that the indices cannot be used interchangeably at this site in their present form. If BOD is included in the IEI this would be possible, although the reduction in the correlation coefficient obtained suggests that the TEPI has problems dealing with multiple processes emitting to a range of media at a site. This despite the rejection of independence between the two indices by all the rank tests (see Table 11.2).

The potential use of the TEPI as a substitute for the IEI as a process option ranking tool is strong at this site. There are no differences between the correlation coefficients for the TEPI and its ranked categories, although the strength of the correlation does drop when BOD is included in the IEI. This factor again questions the validity of the TEPI, especially where very different process options are to be compared. The effect of these differences may become clear when all the processes are compared with each other in the section 11.2.2.

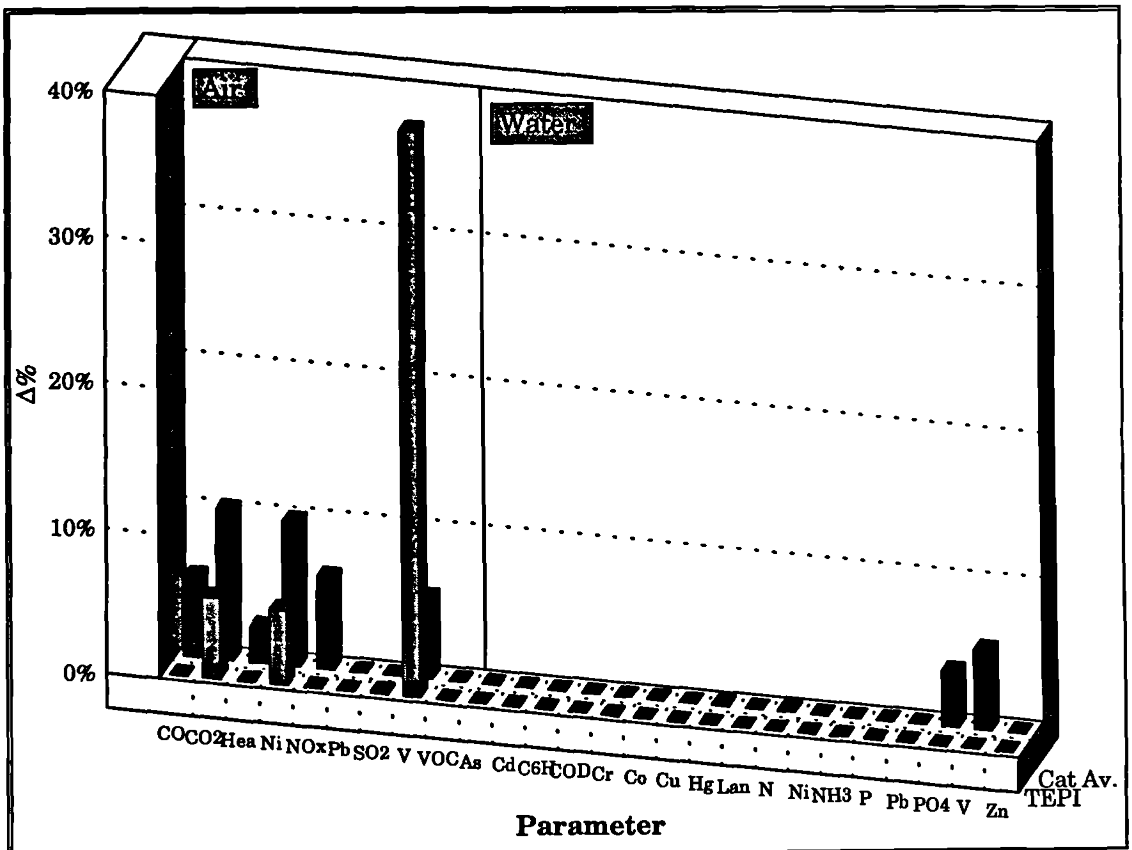


Figure 11.23 - Sensitivity of TEPI and Categories to a 50% Increase in Emissions.

11.2.2 Inter-Company Comparison.

Comparison of the monthly IEI and TEPI values from all of the companies supports the predominantly independent relationships seen within the companies themselves. The data on the correlation coefficients and rank tests on the combined results are shown in Table 11.4 and Table 11.5 respectively. Significant results are highlighted in **bold**.

Table 11.4 - Correlation Coefficient for Combined (Average) Monthly Data.

Parameter	All Sites Monthly	All Sites* Monthly	All Sites Average	All Sites* Average
Crit. Val.	0.188	0.188	0.714	0.714
r	-0.014	0.082	0.019	0.103

* BOD included for calculation of IEI.

Both tables show the results including and excluding BOD in the IEI at Companies C and G, for all the monthly data and the monthly average at each company. The company average has been calculated to exclude the potential effect of relationships between the indices within the companies themselves.

Table 11.5 - Results from Spearman's Rho Rank Test for Independence.

Parameter	All Sites Monthly	All Sites* Monthly	All Sites Average	All Sites* Average
$t_{0.95,n-2}$	*±1.67*	*±1.67*	*±2.02*	*±2.02*
T_R	5.00	4.76	4.19	4.19
H_0	Reject	Reject	Reject	Reject
$T_R^{\#}$	-6.32	-5.93	5.10	5.10
$H_0^{\#}$	Reject	Reject	Reject	Reject

* BOD included for calculation of IEI.
\# Analysis made using ranked TEPI categories.

The correlation coefficients for the process ranking test are shown in Table 11.6, together with their critical values.

Table 11.6 - Correlation Coefficients for Ranked IEI and TEPI values.

Parameter	All Sites Monthly	All Sites* Monthly	All Sites Average	All Sites* Average
Crit. Val.	0.188	0.188	0.714	0.714
r	0.50	0.48	0.64	0.64
$r^{\#}$	-0.59	-0.57	0.71	0.71

* BOD included for calculation of IEI.
\# Analysis made using ranked TEPI categories.

The data for the combined results given in Figure 11.24 suggests the two data sets are independent, with correlation coefficient close to zero and insignificant (see Table 11.4), showing that the two indices could not be used interchangeably at this level.

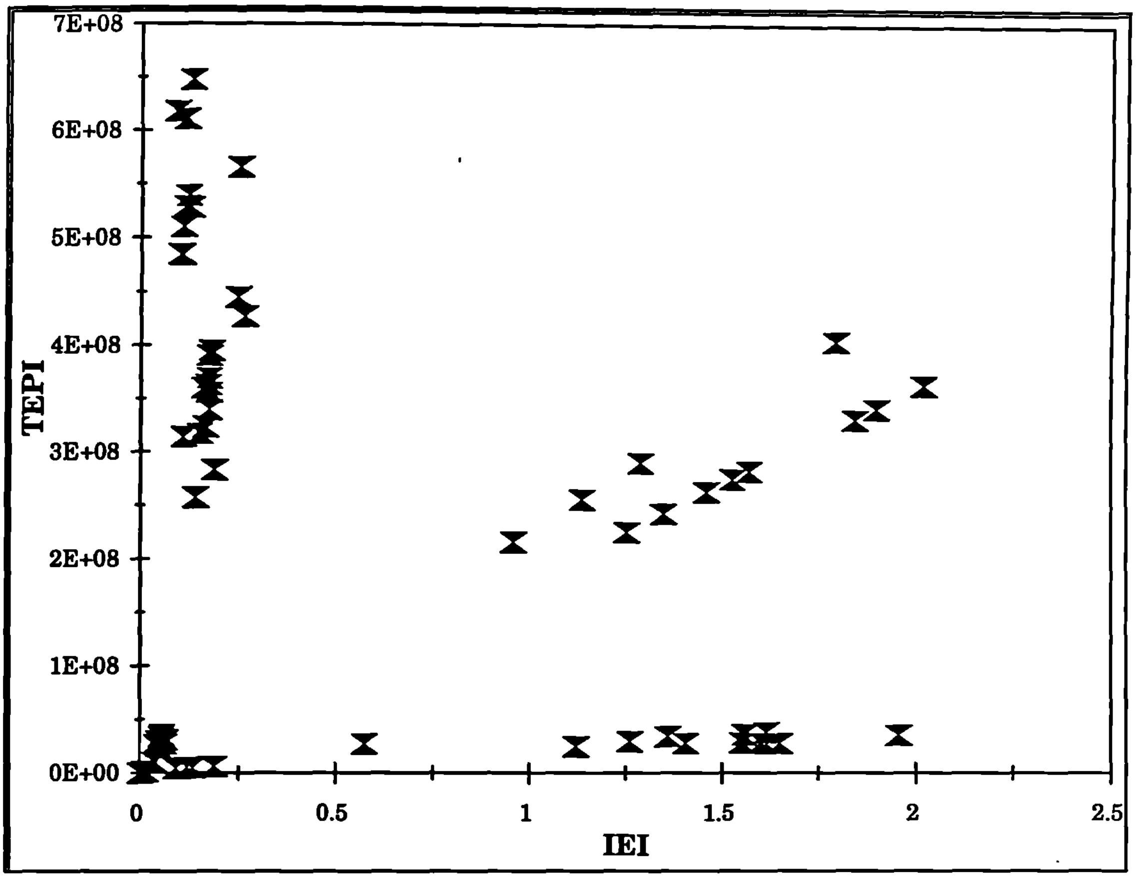


Figure 11.24 - Monthly Values of IEI against TEPI for All Sites.

The rank test for independence does not support this, however, and still rejects the null hypothesis of independence for this data set, using both the TEPI and the ranked categories (see Table 11.5), suggesting that the scale of two indices may be affecting the results obtained. These results are only slightly affected by the inclusion of BOD into the IEI at companies C & G. The final result remains unaffected.

From the intra-company comparisons it has been shown that the relationship between the IEI and TEPI can be affected by both site differences and the additive approach used in the TEPI. This can make it difficult to discern the effect of site differences on the IEI from the statistical analysis. However, by looking at the distribution of points in Figure 11.25 the companies can be split into four groups. Firstly, a group of companies with a low IEI and low TEPI (bottom left).

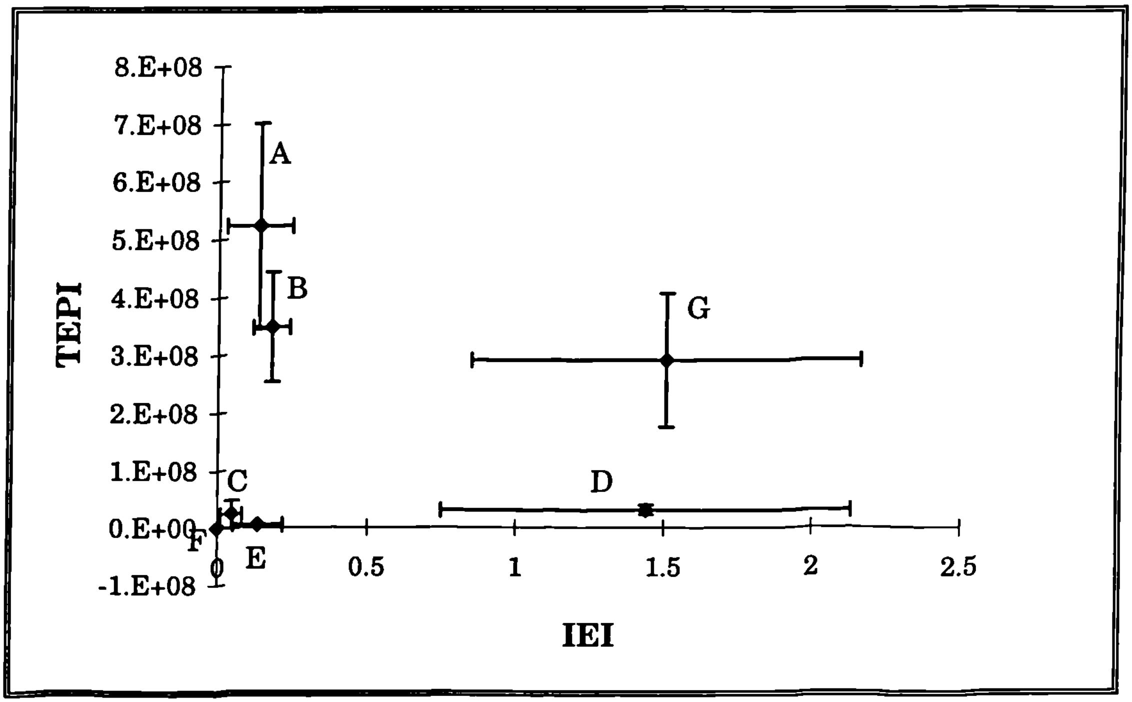


Figure 11.25 - Average & Range of Monthly IEI & TEPI Values for All Companies.

These sites have relatively low mass emissions and use up a small amount of the environmental capacity available. Secondly, a group of companies with a low IEI but a high TEPI (top left). These sites have relatively high mass emissions but due to their location have maintained a low use of the environmental capacity available. Thirdly, a company with a high IEI and a low TEPI (bottom right). This company has relatively low mass emissions but makes a high use of the available capacity. Lastly, a company which has a high IEI and TEPI (top right). This site has relatively high mass emissions which results in a high use of environmental capacity at its location. This sub-division of the sites suggests that site location does have an affect on the outcome of the IEI and compliance based indices.

As the presence or absence of linear relationships present at the individual sites may be affecting the outcome of the combined company data, these influences were removed by looking at the average monthly results for each company. These results, together with the range at each site, are shown in Figure 11.25 . The monthly average data has little effect on the results obtained (see Table 11.4), with the correlation coefficient remaining close to zero. Inclusion of BOD in the IEI for companies C and G increases the correlation coefficient only slightly. The rank tests for independence, however, still reject the independence of the two indices.

The potential use of the TEPI as a process ranking tool, in line with the rejection of independence by the rank tests, is significant yet moderate with little difference between the TEPI and its ranked categories (see Table 11.6), for the monthly index data. For the company average data, which is a more accurate representation of ranking very different process options, the correlation coefficient rises slightly, but due to the small number of data points is insignificant for the TEPI and the ranked categories. This presents only a weak overall case for using the TEPI or its categories as a process ranking tool.

11.2.3 Conclusion.

The graphical and numerical results given above have shown that there is no overall relationship between the IEI and TEPI and that site location does significantly affect the IEI. These effects are, nevertheless, not significantly strong to reject a positive relationship between the indices when using the rank tests.
At a company level some strong relationships have been found between the IEI and TEPI, especially where there are no environmental constraints present at the site. However, these relationships have primarily occurred where one process or set of

emissions dominate both the IEI and TEPI. As soon as additional processes are included in the assessment these relationships fall away, with no relationships present when a wide variety of processes are compared. The TEPI does not cope well with multiple emissions from numerous processes (e.g. fuel combustion and effluent treatment) or from different fuel mixes. It is also predominated by the effects of releases to air, often ignoring significant BOD/COD releases to water. Consequently when highly disparate processes are compared it is evident that overall there is no relationship between the IEI and TEPI. This is also true when the TEPI's ranked categories are used. The IEI and TEPI should, therefore, not be used interchangeably.

Despite the potential effects on the regressional analysis of the additive approach used in the TEPI, the graphical and numerical data show that site location has a significant effect on the comparative results obtained. Company G showed the effect of limited environmental capacity to water, due to the historical location of the site, on the IEI. The opposite effect was shown by companies A and B for releases to air from coastal locations with a large amount of environmental capacity available. Site location, therefore, does significantly affect the outcome of compliance based indices such as the IEI and valid comparisons between sites cannot be made using such indices.

Finally, the case for use of the TEPI as a process option ranking tool is weak. At an overall level the ranked indices are moderately correlated, but given the wide disparity between the results obtained at the companies themselves it would not be advisable to base site-based decisions on the TEPI as it stands at present. However, there may be scope for using the TEPI categories themselves in a more advanced inter-related index.

11.3 Sector Variability.

In addition to the site differences found above, sector variability has been assessed to ascertain whether there are significant differences different companies within the same sector. If this is the case then the present usage of sector average data in high-level assessment tools such as LCA may not be valid. In order to do this a comparison has been made between those sites operating within the power and paper sectors and relevant sector data from a number of sources, usually LCA software.

11.3.1 Paper Manufacture.

The emissions per tonne of paper for four parameters from the two paper companies were compared with those from a number of paper sources in the Pia software, namely nature bleached (NB), swiss kraft (SK), recycled (UWS), and kraft standard (KS). These are shown in Figure 11.26 together with the coefficient of variation (CV) for each parameter across the sources given.

For sulphur dioxide emissions, which show a moderate yet relatively low CV of 36%, Company C had the highest emissions at around 17kg per tonne, with recycled paper giving the lowest at around 6kg per tonne. Company D, which uses low sulphur Scottish coal rather than fuel oil, falls in the bottom 50% with around 10kg of sulphur per tonne of paper produced.

Particulate emissions varied more markedly, with a high CV of 69%. Emissions were highest for nature bleached paper (4.5kg/tonne) and lowest for recycled paper (0.4kg/tonne). Emissions from Company C (1.2kg/tonne) were more than half those of Company D (3kg/tonne).

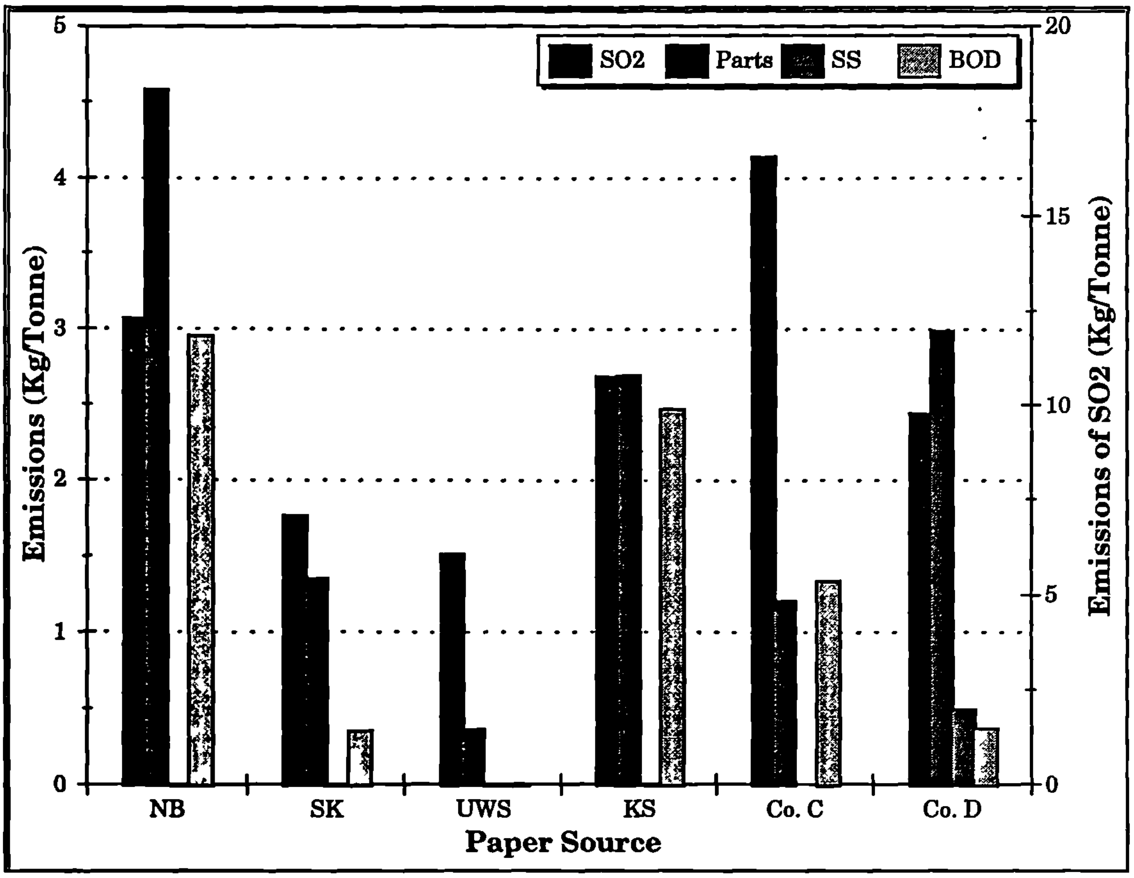


Figure 11.26 - Air & Water Emissions from Companies C & D and the Paper Sector.

Suspended solids emissions to water were consistently low for the Pia sources (0.01kg/tonne). Company D gave the highest emissions (0.5kg/tonne) with no data available for Company C, as the parameter is not required for the IEI. As a result the CV for this parameter is extremely high at 221%. It has not been possible to determine why the Pia sources are all an order of magnitude lower, given the secondary effluent treatment processes present at companies C and D. The low emissions may be linked to higher retention rates within the paper making processes themselves.

BOD emissions also showed a high amount of variability, with a CV of 99%. Nature bleached paper gave the highest emissions (3kg/tonne), with recycled the lowest (0.001kg/tonne). Company C gave moderate emissions (1.4kg/tonne), with low emissions from Company D (0.4kg/tonne).

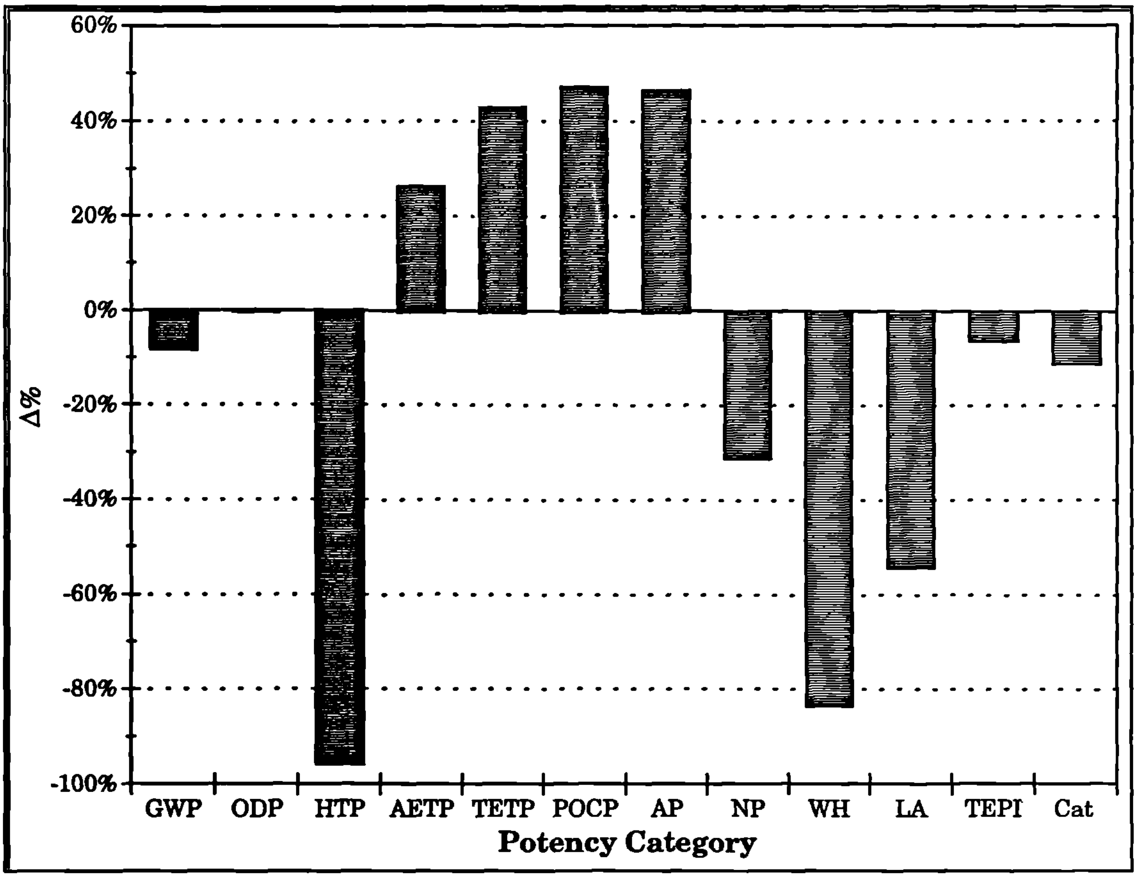


Figure 11.27 - Change in TEPI Categories, TEPI and Category Average from C to D.

The above data suggest a large variation between different paper producers, which are presently not taken into account in many LCA studies. Although differentiations can presently be made between different types of paper, usually from a given geographical area, the variation of the producers within that area are not provided. Looking solely at the two paper companies taking part in this project, a number of differences are also apparent. A change from Company D to C results in a relatively small reduction in the TEPI of 6%. This figure increases slightly to 11%, using the average of the category totals (see Figure 11.27). Examination of the change within the different potency categories shows a more significant amount of change, with reductions in the greenhouse effect, human toxicity and nutrification categories, as well as waste heat and land use, but increases in the terrestrial and aquatic eco-toxicity, ozone creation and acidification categories. Although these changes are difficult to bring together into a single index, and tend to counteract one another when using the category averages, the magnitude of the changes within each category suggests significant differences between the two companies, let alone within the sector itself.

11.3.2 Power Generation.

Within the power generation sector a comparison was made using four parameters, between the UK average generation mix, Scottish Power, Scottish Hydro-Electric and the two power generators taking part in the study. These are given in Figure 11.28 together with the CV for each parameter across the sources given.

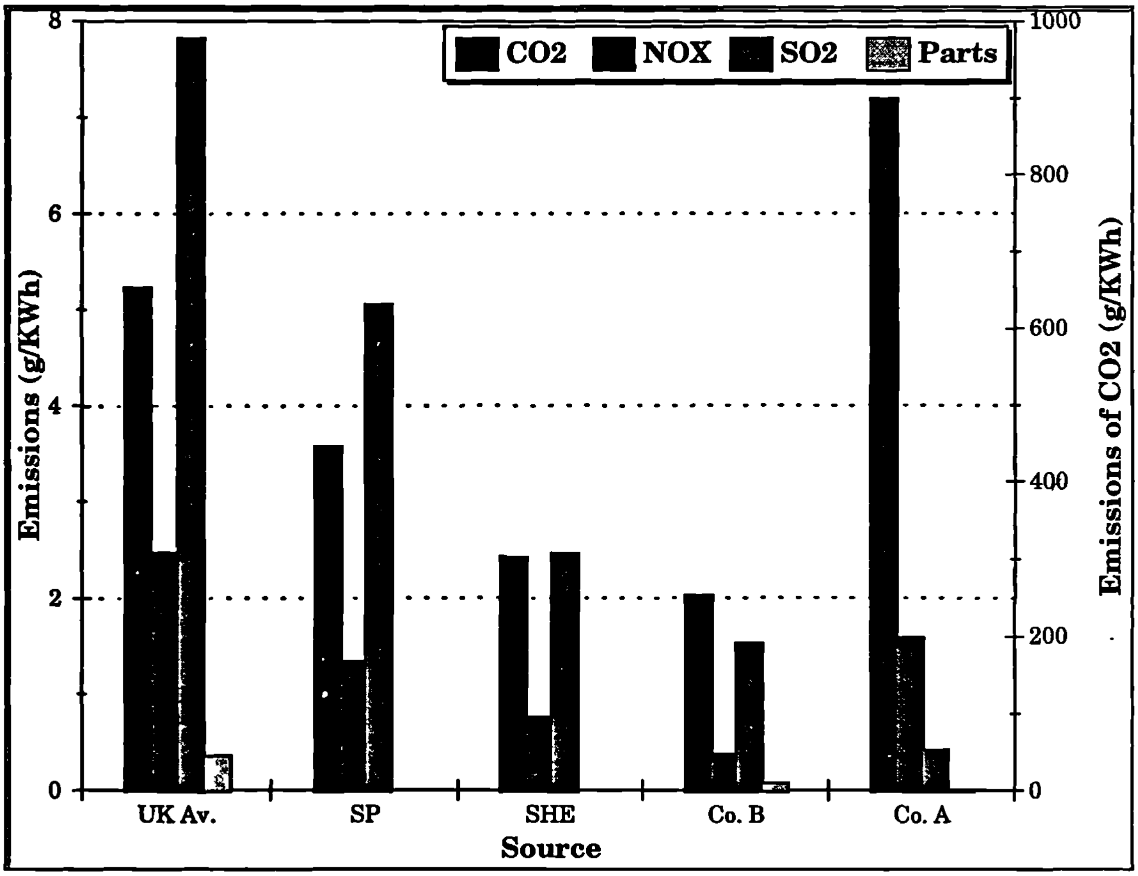


Figure 11.28 - Air Emissions from Companies A & B and the Power Sector.

The quantities of CO_2, NO_x, SO_2 and particulates emitted per KWh of electricity varied greatly between the different sources. For carbon dioxide the highest unit emissions arose from Company A (899kg/KWh), with a gradual reduction from the UK average to Company B (253kg/KWh). This parameter shows the lowest variability between the sources with a moderate CV of 52%. A similar pattern occurs for the nitrogen oxides where Company A is second highest after the UK average (1.6kg/KWh), with Company B having the lowest emissions (0.4kg/KWh). This give a moderately high CV of 62%. For sulphur dioxide the trend changes slightly with a gradual reduction across the sources from the UK average (2.5kg/KWh) to Company A (0.4kg/KWh), giving a high CV of 86%. Emissions of particulates showed the highest variability (CV = 126%) with the highest value for the UK average (0.4kg/KWh) and the lowest for Company A (0.007kg/KWh).

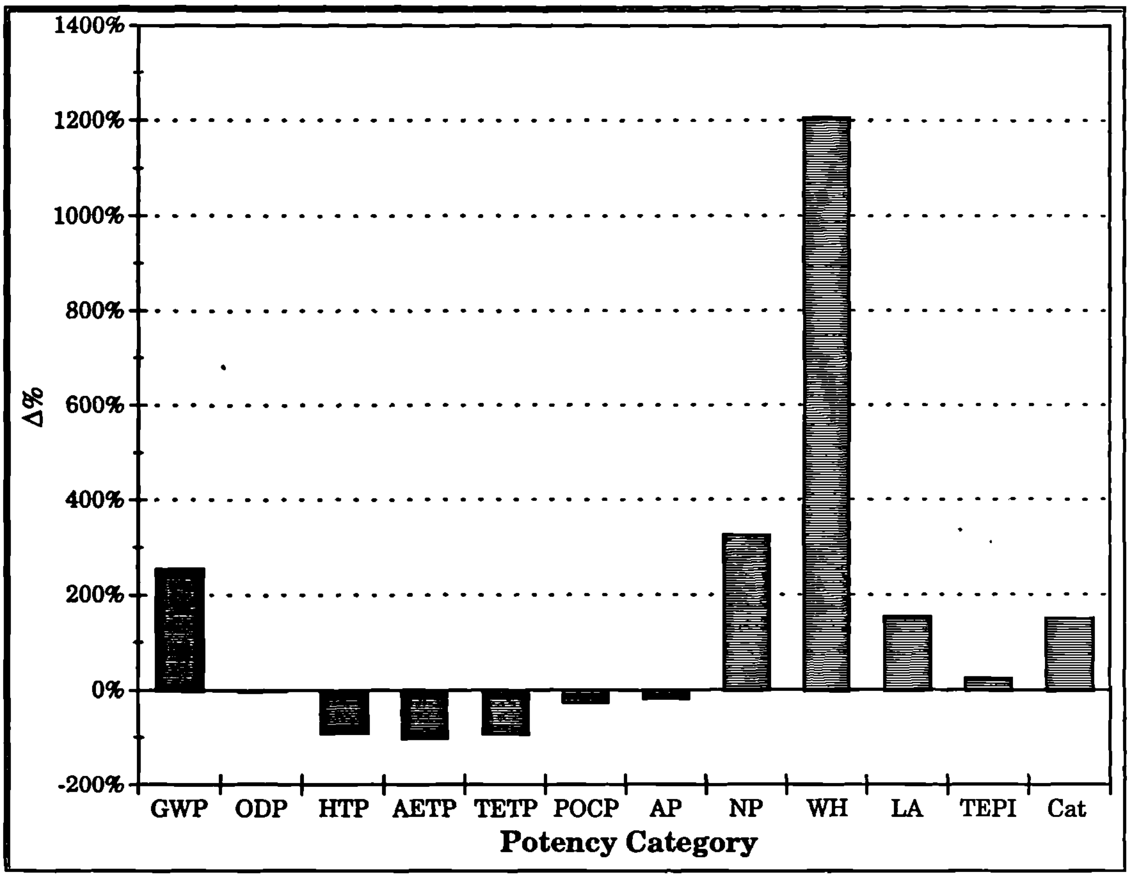


Figure 11.29 - Change in TEPI Categories, TEPI and Category Average from B to A.

No data was available from Scottish Power or Scottish Hydro-Electric on this parameter. The high variation between the different sources can be partly explained by the different generation portfolios that the different generators and the UK average have compared to the fossil fuel plant used at Company A and B. However, a comparison of the impact of the two power stations at Companies A and B shows a 23% increase in the TEPI values per KWh when switching from Company B to A, with a 181% increase in the category average (see Figure 11.29). Much of this is due to the waste heat which is used at the site of Company B but lost to air and water at Company A. However, there are significant changes in the categories, supporting the case for using more site specific data to inform LCA assessments, based on the differences between emissions from power stations burning similar fuels.

11.3.3 Electricity Suppliers.

To test the effect of using different power suppliers in more detail, the contribution of the electricity used by all the companies taking part in the project to their TEPI total and the changes resulting from a switch from the UK average generation mix (UKAV) to either Scottish Power (SP) or Scottish Hydro-Electric (SHE) was assessed. Using the TEPI, the contribution of electricity use to the total environmental burden varied between 5 and 90% (see Figure 11.30).

This difference can be clearly split between those companies that generate most of their own energy requirements (companies B, C D & G), often as heat, and those who are more reliant on machinery powered primarily by electricity (companies E & F). Company A has not been included in the assessment as it is a sole power generator which does not import any electricity for internal use.

Using the category average, which tends to factor out the effects of a TEPI dominated by the greenhouse effect or toxicity categories, a similar picture appears, with the UK average contributing more to the paper companies (C&D) and a little less to E and F, compared to TEPI (see Figure 11.31).

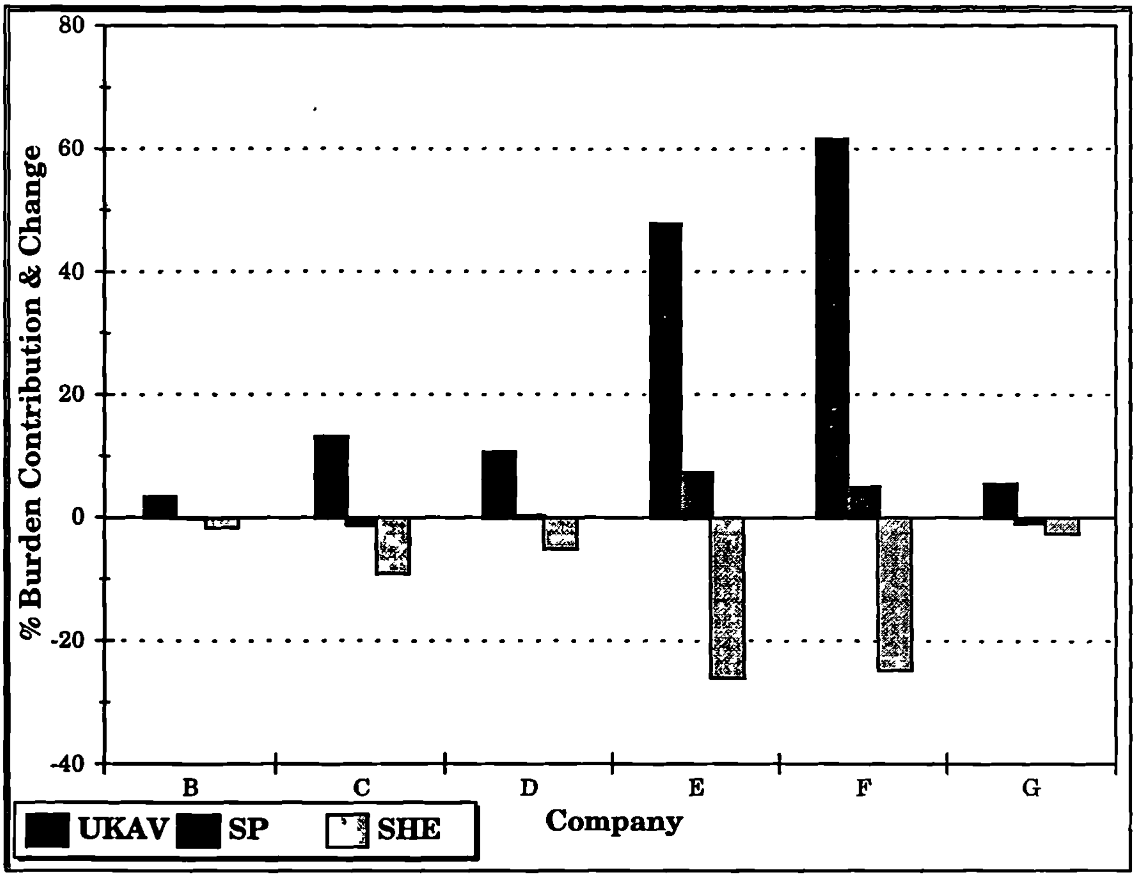


Figure 11.30 - Contribution & Change to Total Burden at Companies B to G (TEPI).

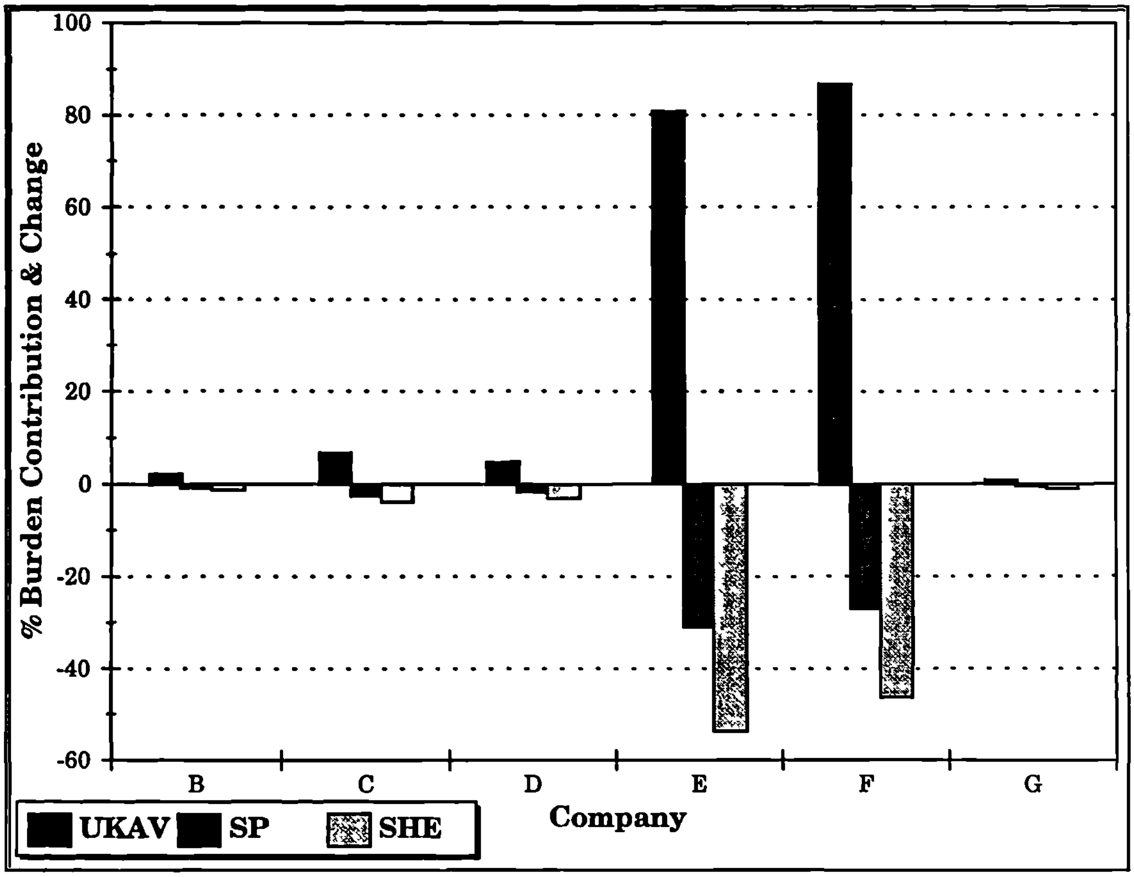


Figure 11.31 - Contribution & Change to Total Burden, using Category Average.

The consequences of changing from the UK average generation mix to Scottish Power or Scottish Hydro-Electric differ slightly between the TEPI and category average, and in the significance this has on the company using the electricity. Using the TEPI there is a reduction in the total burden for all the companies when switching from the UK average to either Scottish Power or Scottish Hydro-Electric. For companies B, C, D and G this reduction is relatively small at around 2% of the total burden. For companies E and F, which use a large amount of electricity but also have a relatively low burden, a switch results in a reduction of around 30% for Scottish Power and 50% for Scottish Hydro-Electric. For all companies, however, there is a marked difference between the reductions obtained from Scottish Hydro-Electric compared to Scottish Power. This reduction is almost double for all companies, suggesting a significant advantage, not only to using company specific data compared to UK average data when assessing electricity suppliers, but also between the specific electricity companies themselves.

When the category averages are used a slightly different picture emerges, depending on the environmental burden present at the site using the electricity. In this case, many of the companies actually experience an increase when changing to Scottish Power. This is due to the fact that for Scottish Power there are both increases and decreases in the potency categories of the TEPI, which will depend upon the contribution of the company to that category. Therefore, some companies show a slight increase and others a decrease, with many of the category changes cancelling each other out. A change to Scottish Hydro-Electric using the category average results in a much more dramatic reduction for all the companies, with reductions of around 25% for companies E and F.

The above data has suggested that there are significant differences between the environmental burdens from different operators within the paper and energy sectors. The UK electricity sector has shown that, depending on the environmental burden of the company, the choice of electricity supplier can significantly effect its total burden. It is important, therefore, to use company specific data when assessing the environmental burden of suppliers and including variance data when carrying out an LCA. Presently this does not occur. The TEPI may be an appropriate tool for aggregating such data.

11.4 Process Variability.

The variability of the IEI and TEPI results obtained from each of the companies has been assessed to establish whether a monthly assessment of environmental performance would be more appropriate than an annual one. This is likely to vary from one company to another, depending on the continuity and range of products being manufactured. The variability of the indices within a given period may also be used to assess the effectiveness of the environmental management systems present at the site.

The variability of the monthly index values has differed both between companies and between the indices used to assess them. Figure 11.32 shows the coefficient of variation for the IEI, TEPI and potency category average for companies A to G. This figure shows three groups of companies with a low, moderate and high relative coefficient of variation. Firstly, companies B and D show a relatively low CV at around 15 %, with companies E, F and G having a moderate CV around the 20% mark, leaving companies A and C with a high CV of around 40%. The relationships between the different CVs present for some of the companies is best explained by looking at the companies separately.

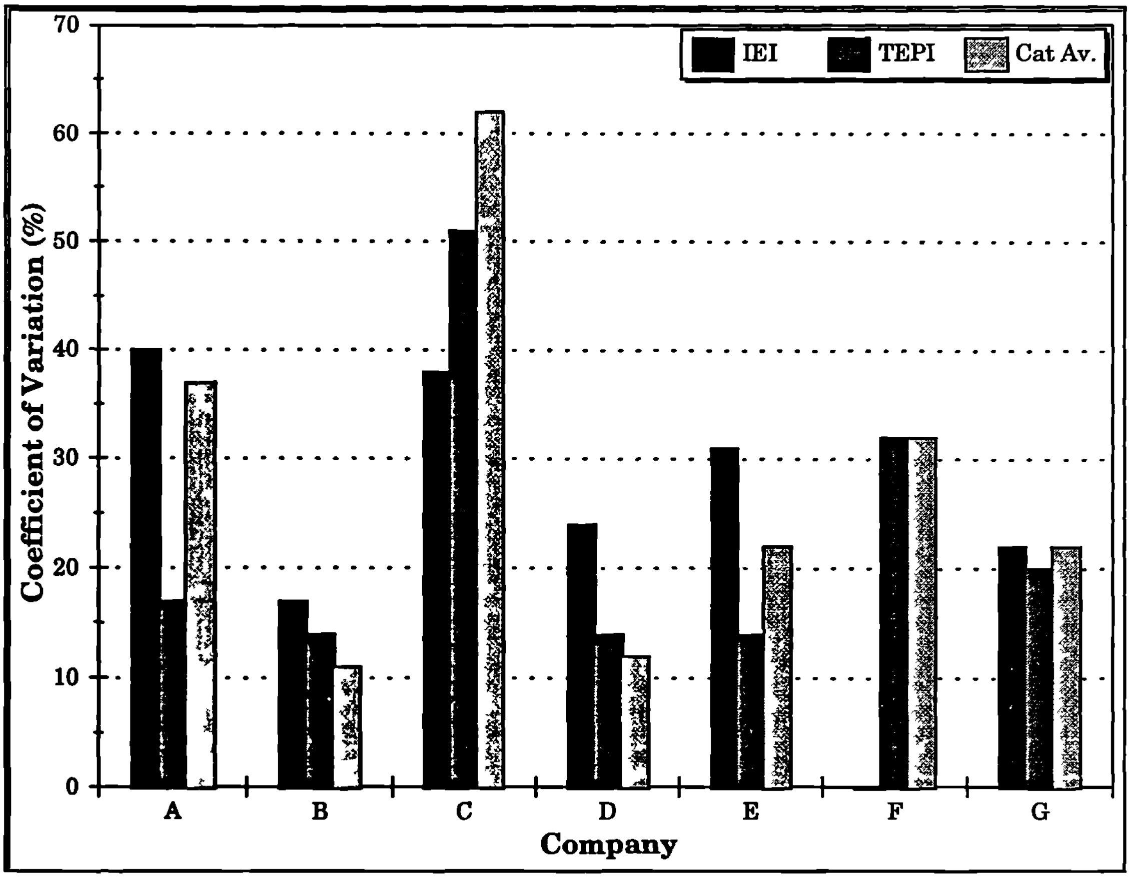


Figure 11.32 - CV of IEI, TEPI & Category Average for Companies A to G.

Compared to the other companies, Company B shows a low overall variability, with only small differences between the indexing methods used. The CV for TEPI at this site is slightly lower than the IEI. This may be due to the lower variability of the CO_2 emissions from the site, which contribute to the greenhouse effect category. These emissions are not included as part of the IEI, which is dominated by emissions of SO_2 and NO_x. The CV for the category average, which quantifies the average variation across the TEPI categories to assess whether the additive approach may be affecting the TEPI results obtained, is slightly less due the low variability in the toxicity categories from the more consistent releases to water. The two indices, therefore, agree that the variability of emissions is low when using a monthly time-scale.

Company A presents a less consistent picture between the IEI and TEPI, with a high variability in the IEI and a low one in the TEPI. However, when the category average is used this appears to confirm the high variability present within the IEI. This suggests that the differences between the two indices may not be due to site location, but due to the TEPI itself. The TEPI for company A is dominated by the greenhouse effect category which accounts for 94% of the TEPI total (see Table 4.17). The low amount of variability in CO_2 emissions from the site, which are the main contributor to this problem, account for the low CV of the TEPI total. When the variability across all the categories is taken into account using the category average then the IEI and TEPI appear to agree.

Company C shows a high rate of variability in all the indexing methods used. The IEI at this site has a CV of 38%, which falls to 20% when the BOD, excluded for releases to estuaries, is included. The IEI for Company C is dominated by releases to air which are highly variable, in the form of SO_2, NO_x and particulates. Those releases to water which are covered have only a very small effect on the index total such that any variability in this data would have little effect on the final index result. However, the primary burden to water from the site is due to BOD emissions, which are presently excluded from the IEI. If BOD emissions are included in the assessment, using the EQSs for emissions to riverine surface waters, then the variability of the IEI actually falls to 20%. This is due to the damping effect of a parameter which has a large effect on the IEI combined with a lower CV. The TEPI and Category average also show a high variability for Company C, with the category average having a higher CV than the TEPI. This confirms that the high variability from the TEPI is not due entirely to the effect of one category or the emissions of one substance from the company. The emissions are dominated by releases to air from the site, but these releases contribute to a wide range of environmental problems. The site characteristics for this company suggest that the IEI and TEPI do agree that the variability is high, although they differ in the extent of that magnitude. However, if BOD releases are included this ceases to be the case, with the IEI suggesting only a moderate amount of variability.

Company D shows distinct differences between the two indices, given the similarities between the TEPI and category average. This is highly likely to be due to the local environmental restraints on the IEI, causing one parameter or medium to dominate the index. The IEI at Company D is dominated by releases to water in the form of BOD and copper, both of which have a high CV. These parameters dominate the IEI due to the relatively low dispersive capacity available in the riverine surface waters to which the company discharges. The TEPI and the category average both have a relatively low CV and thus support each other. Company D, therefore, suggests that the IEI and TEPI do not agree due to site restrictions on the IEI.

Company E appears to be similar to Company A, showing a disagreement between the IEI and TEPI, although the category average suggests that the TEPI is underestimating this variability. The TEPI again dominated by the greenhouse effect with low variability CO_2 and N_2O emissions, is disproportionately affected by the low variability of the former. In contrast to this the category average shows a higher average variability among the categories giving a moderate variation for the site. Either site differences or the effects of substances not covered by both indices have resulted in the difference between the IEI and category average. At this site the IEI and TEPI appear not to agree on variability, which should be high as predicted by the IEI and category average. These results support the acceptance of independence by the rank test in section 11.2.1, despite the high R^2 between the two indices.

Company F had no significant releases to warrant assessment using the IEI, but does show a consistent variability between the TEPI and the category average. This is due to the fact that the variability of the greenhouse effect category, which dominates the TEPI, is similar to that of the other categories used to calculate the category average.

At Company G there appears to be good agreement between the two indices, similar to that found with company A. The IEI from the site is dominated by emissions to air, which also dominate the TEPI and have similar CVs. However, the IEI presently excludes BOD emissions to estuarine surface waters, which if included drastically increases the variability of the IEI to 40%. In contrast to Company C, the inclusion of BOD, which is a highly significant variable with a high CV, causes an increased variability in the IEI total. At Company C the CV was reduced as its releases of BOD are more constant. This reduction in the agreement between the two indices when BOD is included in the IEI at both these sites ties in with the disparities seen in section 11.2.1.

These results show that site location can affect not only the IEI for that site, but also the variability of the index. Where emissions from a site are restricted by a medium, in the above companies this is usually to water, this can cause the CV of the IEI to be dominated by the variability of the parameters released to that medium, where the TEPI or category average would show the variability within a generic environment. However, the present set-up of the TEPI has meant that the index can also be disproportionately dominated by categories which do not represent the generic variability of the site. Where there are no known site restrictions on emissions, and a site would be expected to equate with the generic state index the TEPI has still differed significantly from the IEI. This was evident at Company B, which has a large amount of dispersive capacity available, but for which the TEPI and IEI still vary significantly. The category average showed that there is a high amount of variability within the TEPI categories themselves, which corresponds to that found in the IEI. However, the TEPI which is dominated by the low relative variability of the greenhouse effect category suggests an overall low variability. Most of the TEPI values are dominated by the greenhouse effect or toxicity categories, which can presently not be physically related to each other. This may make the TEPI less useful as a holistic assessment tool.

Overall the variability of emissions differs greatly between the participating sites. For those with very a high CV, this may warrant a more detailed assessment of the causes of this variability and the time-scales over which environmental performance is measured. However, there will by physical and financial limitations to the frequency at which this can be done. For those with a more continuous set of emissions it may be more appropriate to assess their environmental performance on an annual basis.

11.5 Data Accessibility.

The accessibility to the emission data required for the indices, or to approximate those emissions, was assessed by examining the material and energy flowing through the companies, the parameters required by the indices and the constituent data used to estimate emissions from product data.

11.5.1 Material and Energy.

The accessibility to the materials and energy flowing through each of the companies taking part was assessed using the four categories discussed in section 3.7.4. The percentage of each flow falling into these categories [High (H), Moderate (M), Low (L) and Inferred (I)] was calculated for both the input and output flows.

The energy flows for each of the companies are shown in Figure 11.33 and Figure 11.34. Five out of the seven companies have highly or moderately accessible energy usage figures for their sites, with Company F and B being the exception. At Company F this data was not collected at the time of the study and had to be dug out from invoices. At Company B the energy content of the fuel is not measured as the plant has been designed to use up waste fuel oil and gas from an indigenous source to generate electricity. Any shortfalls are supplemented with electricity from the grid. As a result the data had to be inferred from usage figures and sample calorific values. The high amount of highly or moderately accessible data reflects the relative importance of energy use in the present accounting system of the companies concerned, where it has been an important cost item for some time.

The energy output data in Figure 11.34 shows a reduction in highly or moderately accessible data amongst the companies. Where this data is accessible this tends to correspond to electricity usage on the site, which has been assumed to balance across the site's boundaries. Physical measurement of energy outputs rarely takes place at any of the companies, with the exception of power from Company A. At other companies, which generate a large proportion of their heat energy on-site, the energy lost from the system is not measured directly but has been inferred from efficiency data for the boilers or processes concerned.

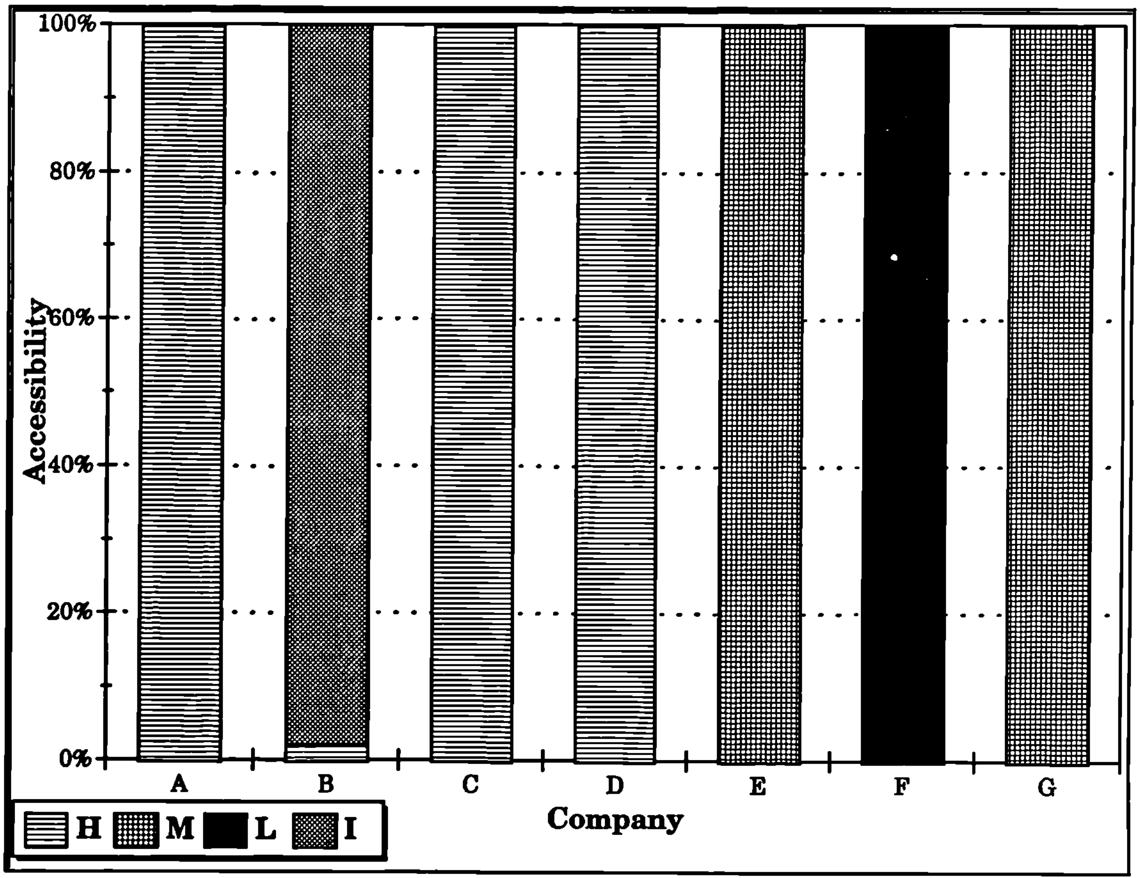


Figure 11.33 - Accessibility to Energy Input Data for Companies A to G.

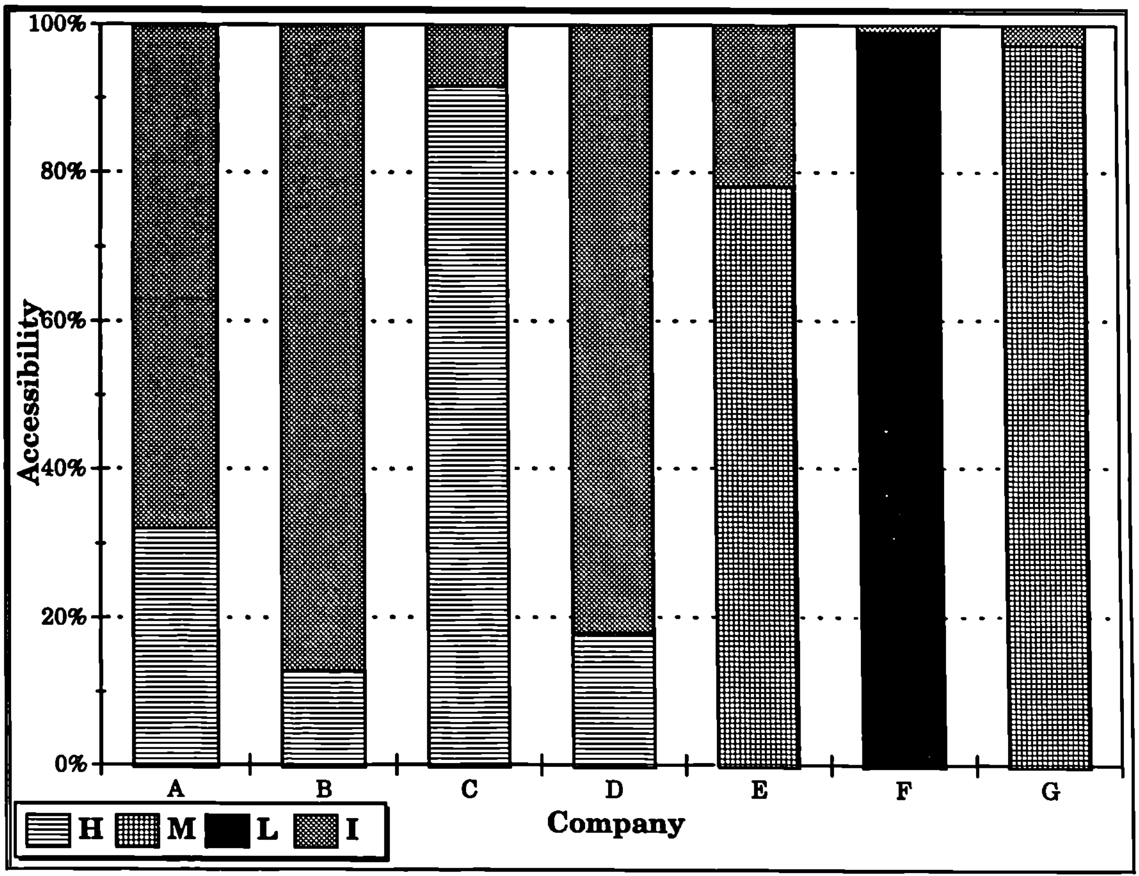


Figure 11.34 - Accessibility to Energy Output Data for Companies A to G.

For the two indices, emissions of heat energy from the sites have been less important than material emissions, only contributing to one of the TEPI categories.

The material accessibility data is shown in for all the participating sites. The mass material input accessibility has also been very good for the majority of companies on the project, with an average of 50% highly or moderately accessible data. With all companies generating some of their own energy using fossil fuels, much of the inferred inputs refer to the air taken into the system to combust the fuel. Data on the actual materials used by almost all of the companies have generally been readily available. The exception to this is Company F, where the data was not centrally collected at the time of the project. All other companies either had highly or moderately accessible data, reflecting their well developed material cost accounting functions. The accessibility to the materials emitted from the sites varied greatly between the companies. Companies D and E had a very large quantity of highly or moderately accessible data. For others, emissions had to be almost entirely inferred from other data, as in companies A, B and F. The remainder, C and G, have a mixture of moderate or low accessible and inferred data for their sites.

In only one case did the high accessibility to data reflect the production of an environmental report by a site (Company D), with many other sites having a high percentage of moderately accessible data (i.e. in internal reports). This was true at Company E which produces a series of emission metrics, but does not report these externally. The remaining data which did not need to be inferred was collected as part of a consent on the relevant release to air or water. The above data suggest that the electronics, paper and perhaps the food industries taking part are best placed to provide information for the indices used, without the additional expense

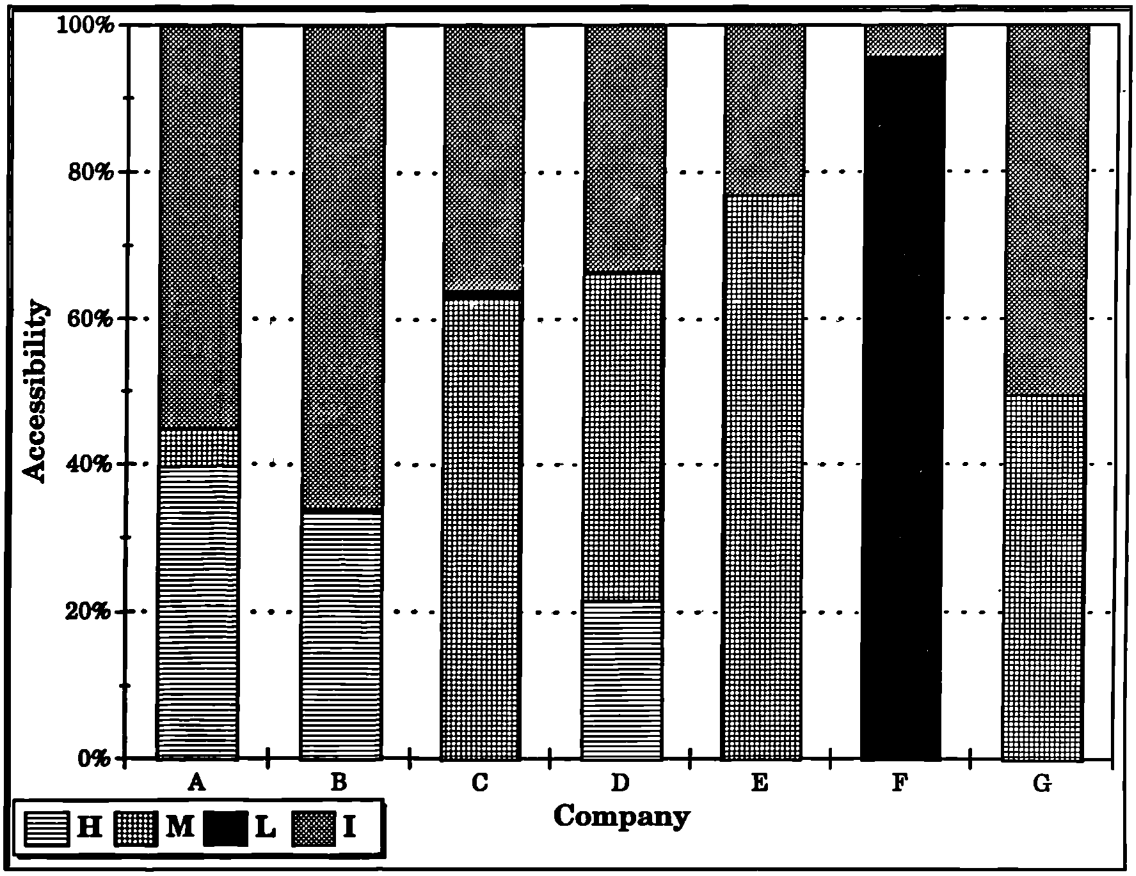


Figure 11.35 - Accessibility to Material Input Data for Companies A to G.

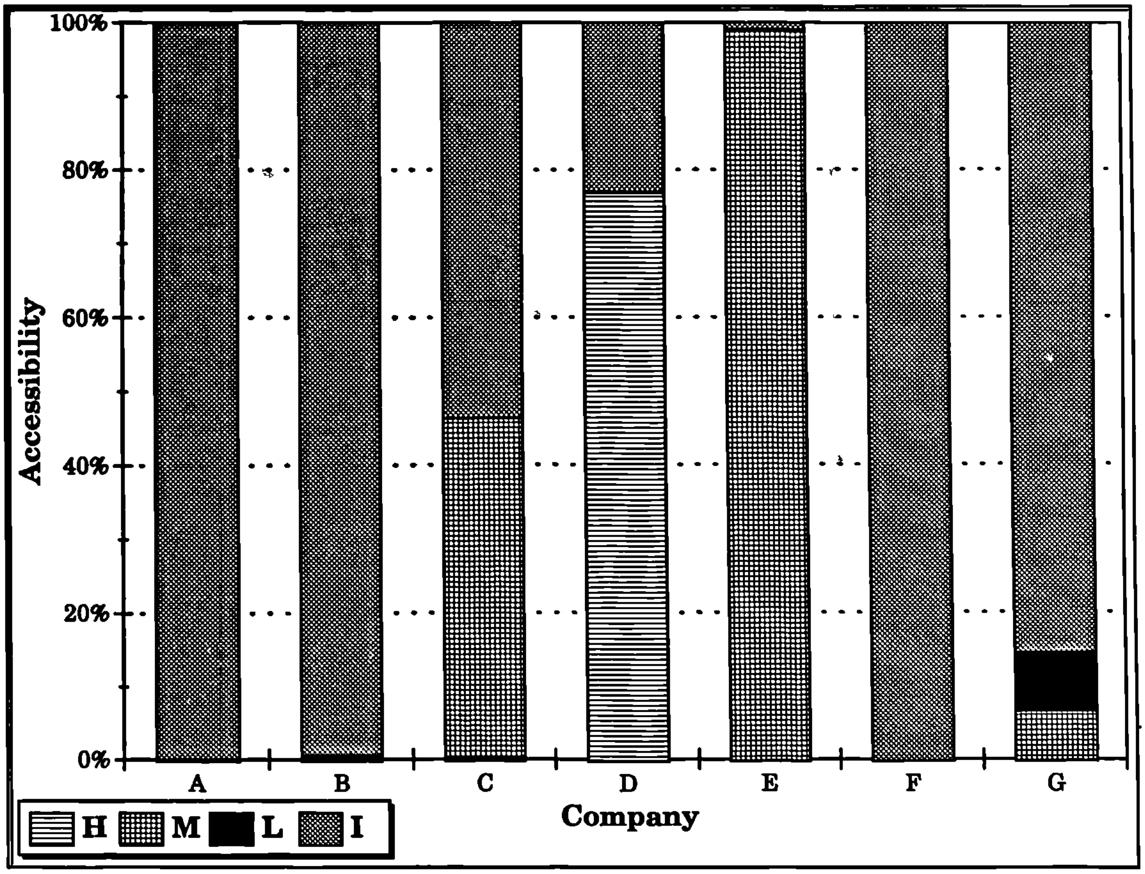


Figure 11.36 - Accessibility to Material Output Data for Companies A to G.

for their collection. This does not appear to be the case for the power and textile companies.

11.5.2 Parameters.

An assessment of only mass emissions often results in one parameter dominating the release of others in the assessment. For example, at company A carbon dioxide is released in far higher quantities than sulphur dioxide and the nitrogen oxides, thus suggesting that the very little data is accessible at the company. To take account of this the accessibility of the output data required by the TEPI and IEI was assessed separately based on the number of parameters rather than mass emission data. The results for the IEI and TEPI at all the companies are shown in Figure 11.37 and Figure 11.38 respectively, together with the number of employees at the site and in the organisation as a whole. Using the parameter approach the percentage of highly and moderately accessible data has decreased to below 20% of the parameters covered by the IEI, with only Company B and E having accessible data above this. For TEPI the picture is similar, with only Company E having accessible data above 20%. This suggests that the IEI would be best suited to the data presently available at companies, with all but one having to collect or estimate emission data for over 80% of the parameters covered by the TEPI.

11.5.3 Constituents.

The final assessment of data accessibility concerns the constituent data used to infer emissions from companies using mass balance studies based on product usage data.

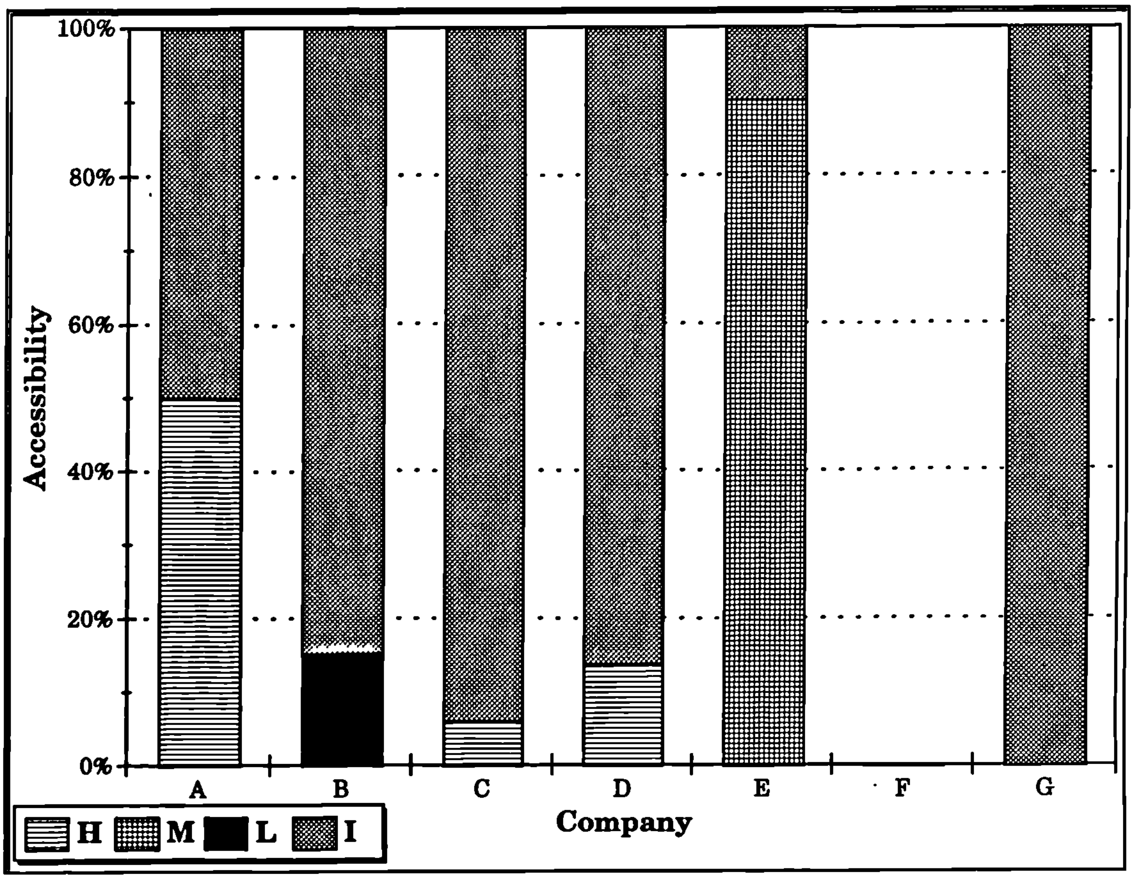


Figure 11.37 - Accessibility to Emission Data for the IEI at Companies A to G.

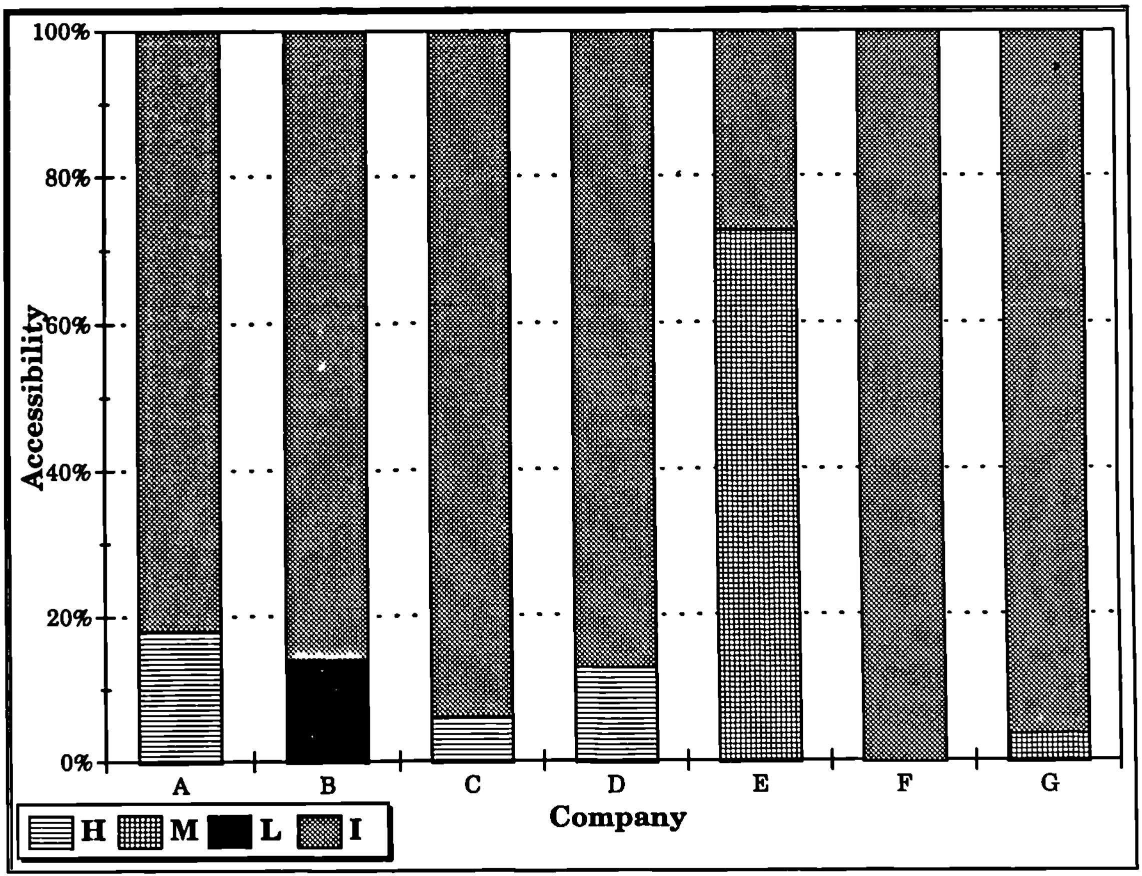


Figure 11.38 - Accessibility to Emission Data for the TEPI at Companies A to G.

To assess the potential for companies to use this approach to estimate emissions, where sampling is impractical or too expensive, the availability of the constituent data was examined.

Constituent data derived from material safety data sheets does not always cover all the substances present in the product. Therefore, the average amount of unknown material for the products used at each of the companies was estimated to assess the magnitude of unknown material emitted from the system. Figure 11.39 shows the average percentage of unknown material in the products used at each of the companies, the percentage this forms of the total material flowing through the system, and the mass of unknown material released to water from the companies in tonnes.

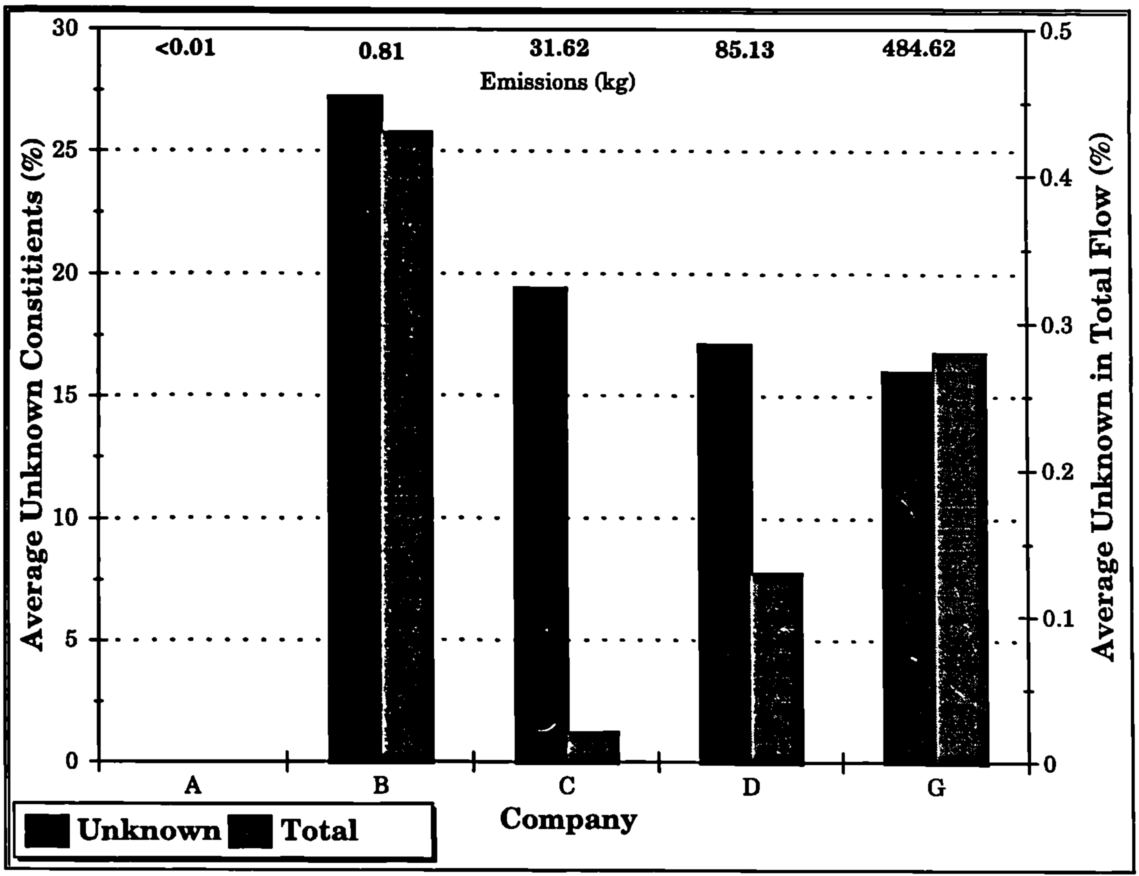


Figure 11.39 - Unknown Emissions as part of Product, Total Flow & Mass Output.

The average percentage of unknown material in the products used within the paper and food companies appears to be reasonably consistent at around 17.5%, with the power companies showing large disparities in data availability. Company A has a relatively high average unknown content at 27%, in contrast to Company B which has an almost negligible amount of unknown substances. The proportion of the total flow of the unknown materials is variable but very low for all the companies, fluctuating between near zero and 0.4%. However, due to differences in scale of the operations these small proportions give rise to very different quantities of unknown materials released to water from the companies.

Releases from the power companies were low, where materials are used only to prevent corrosion in pipes and cooling equipment. The paper companies with monthly emissions of 32 to 85 tonnes of unknown material released relatively moderate amounts, with the highest from the food company with average monthly releases of 485 tonnes. Given that prescribed substances need to be quoted as part of any Material Safety Data Sheet, these unknown materials are likely to include non-prescribed trace metals as well as water and inert bulking material. The potential effects of these materials, especially for Company G, are high, although the releases will be made up of wide mixture of substances.

Overall, therefore, constituent data is readily available for the products used by the companies, with up to 82% of the constituents being quoted on average. This suggests that where there is a high percentage of easily or moderately accessible data, as for companies C, D, E and G in Figure 11.35, a mass balance approach may be a practical way of estimating emissions which are not currently measured.

11.6 Conclusion.

The data analysis has shown that the IEI and TEPI cannot be used interchangeably and that the two are significantly different. Site location was the primary overall cause of this and does have a significant effect on the use of compliance or site-specific impact assessment methodologies. As a result a different impact assessment tool would be needed to assess data from different sites. The TEPI may be able to play a role in this, although the additive approach presently used may not be appropriate. Use of the category average showed that the TEPI is not always able to respond to those significant environmental burdens present, being disproportionately dominated by a single category. The category average was able to give a more realistic yet incomplete feel for the priority burdens from a process.

The appropriateness of the time periods chosen to collect the data varied between companies, with a weekly assessment being more appropriate at some of the sites. Variations between companies within a similar sector were high, also suggesting that the present sectoral approach taken in LCA may be inappropriate, with a more detailed approach being required. Companies may, therefore, have to produce potency data at a company level, rather than using sectoral average emissions data to calculate these as part of an LCA. The required emission data was generally not highly or moderately available, especially when assessing the parameters required for the two indices. The basis for inferring these emissions from input data using mass balance studies is good, both in terms of input data accessibility and constituent data availability.

CHAPTER TWELVE

Perspectives & Futures

Indices in Environmental Management

12.1 Introduction.

This chapter discusses the implications of the results on the appropriate areas of use for the two indices, both within the process information life cycle and product assessment tools such as LCA. The potential for further development of the indices is discussed and an initial framework on the appropriate use of site-specific and generic data and impact assessment is put forward. From these a number of research needs are derived.

12.2 The Process Information Life Cycle.

The previous chapter has highlighted the influence of location on site-specific/compliance based indices. As the amount of available environmental capacity can vary from one location to another, indices such as the IEI, which are calculated based on local dispersion, can significantly disadvantage companies operating in low capacity environments. This does not remove the need for a system that ensures local no effect limits are met. However, it does suggest that a more generic environmental performance index would be more appropriate when comparing a variety of sites.

12.2.1 Site Application.

Comparison of the ranked index values from the IEI and TEPI has suggested a moderate case for the use of TEPI as a site application tool.

The IEI, the comparator for TEPI, has been specifically designed as a site application tool as part of the BPEO assessment methodology (see section 2.3.3). The primary function of a such a tool is to rank a series of process options for a manufacturing process according to their environmental impact in the locality of that process. This study has examined the effect of site location on the interchangeability of the indices and the use of TEPI as a process ranking tool. The ranked index values calculated across all the companies studied gave a significant moderate correlation coefficient (r≅0.50) between the IEI and both the TEPI and its ranked categories (see section 11.2.2). This improved if the average monthly data was used (r≅0.67), but due to the small number of data points is insignificant. As a result there is only a weak overall case for using the TEPI as a ranking tool. In order to function consistently it must also give similar results at specific sites. Although the correlation coefficients at each company have generally been high, a number of problems have affected the ranked indices. These problems have been caused by both site limitations, which caused disparities between the IEI and TEPI at Company D (see section 11.2), and process fuel mix changes, which resulted in the low correlation coefficient at Company B. The latter also shows disparities between the TEPI and its ranked categories which were again found at Company E. Consequently, the IEI and TEPI presently do not give consistent results across the companies studied in this project.

The above disparities suggest that a mass emission approach to site application can presently not guarantee consistent results at a range of different sites. The site-specific results, however, are based on a limited number of data points. Data derived over a longer period of time - i.e. a number of years - or in more detail - i.e. weekly - may give more consistent results. Even when there is a high correlation coefficient between the indices, there remains a major practical problem in using the TEPI as a site application tool. Although the TEPI can be used to rank different process options, it cannot ensure that these do not exceed the EQSs or EALs in the local environment. The dispersion of the process emissions would,

therefore, still have to be modelled in the local environment. As a result, two different approaches would be used to achieve the same result as the IEI.
The initial screening of process options based on mass emissions followed by detailed modelling of the final option, is also undertaken as part of the BPEO assessment methodology proposed by the CIA (1995a), as discussed in section 2.3.3. This approach does not ensure that the optimum use is made of the local capacity, which is what the IEI aims to ensure. This is a particular weakness of the CIA methodology, whose categories do not even examine the potential impact of releases, as occurs within each of the TEPI categories. The CIA categories look solely at the number or total quantity of emissions within a category, rather than their relative contribution to a problem. For example, the number of VOCs handled says very little about the relative potential or actual impact of the different gases within that category. Certain process options, which would have given a lower overall impact using the IEI may be excluded as a result of this method.

The emissions could be better screened using the simple dispersion algorithms to calculate a rough IEI for the initial process options. Although simple, these algorithms do take account of the primary site-specific variables affecting the local dispersion of a pollutant - i.e. the stack height for releases to air and river/estuary discharge for releases to water. A short-list of options could then be modelled in detail to derive the IEI.

Given the need to ensure local limits are not exceeded and the inconclusive relationship between the IEI and TEPI, a mass emission or potential impact assessment technique may not be appropriate for use as a site application tool. This confirms the recommendations made in a conceptual study by WRC (EA

1997b), examining alternative assessment techniques for use in process selection. However, no data was used as part of this study.

On this basis the IEI is the most appropriate integrated assessment tool available for site application in the UK to date. The methodology does have a number of limitations, which are discussed in section 12.3, together with those of the TEPI. As a result of the criticisms received because of these limitations the BPEO Assessment methodology has been published as guidance only, with the IEI broken down in to its Environmental Quotients for air, water and land. Given the integrated aims of IPC under which it was devised, this somewhat defeats the objective of integrating releases to different media into a single measure of performance or impact.

Actual use of the BPEO assessment methodology to date has been limited, which is demonstrated by the relatively low data accessibility for those parameters required by the IEI at each of the companies taking part, the majority of which are subject to IPC. The intermittent nature of IPC applications and the small number of parameters that must be measured as part of a consent have also contributed to the small amount of accessible data. Nevertheless, the high percentages of input parameters which are measured as regularly as once a week, and the large amount of product constituent data now available, would allow the easy use of mass balance studies to predict those emissions not normally measured (see section 11.5).

12.2.2 Site Management.

Present site management techniques, using an Environmental Management System (EMS), employ a ranking tool based on Risk Assessment to prioritise the environmental effects. A subjective matrix is used to bring together a wide variety of environmental issues or aspects. This system is used primarily because it is not as time consuming as the more quantitative studies carried out for product development or process applications. It is also able to incorporate qualitative issues into the assessment. The ranks obtained from the system cannot distinguish between significant and insignificant effects, simply producing a list of priorities.

Both the IEI and TEPI may be able to provide a more quantitative approach to site management, giving relative rather than ranked values for the effects of a site on its surroundings. The use of the IEI or TEPI for site management depends on the significance of site location between the indices. To be valid an index must represent the true environmental effects present at the site.

Comparison of the IEI and TEPI in section 11.2 has shown that site location does affect the IEI significantly and that the index values of the IEI and TEPI cannot be used interchangeably. Although strong relationships were present at some of the participating sites, the overall comparison of the indices rejected a positive linear relationship ($p>0.05$) between them (see Table 11.1). The sensitivity analysis of the two indices supports this, with the two indices being driven by different emissions at each site. Consequently, the TEPI would not be able to measure or respond to the primary impacts present at a specific site.

Given the significance of site location in determining the extent of impact, the IEI may be able to play a role as a site management tool. The index responds well to local environmental capacity, although it does presently exclude a number of regional and global issues.

The calculation of the IEI on a regular basis can also be expected to have a long feedback time, especially for releases to water. This as the modelling software used to estimate the maximum environmental concentrations for releases to air and water as part of the project had to be operated separately from the spreadsheets used to estimate emissions and calculate the IEI. As these models use a number of variables which affect the maximum concentration of a given release rate or effluent concentration, such as stack temperature and effluent volume, no simple linear relationship exists between the location with the maximum average annual concentration and the release rate or concentration. Consequently, simple algorithms could not be used to make predictions from release data as part of the spreadsheet. This makes the IEI less useful as a real time assessment tool for a site's environmental management. However, where the variability of emissions from a site is low and can therefore be assessed on a monthly basis, as occurred at a number of the project sites, the IEI could be used to calculate monthly metrics of environmental compliance/capacity use.

As process variability is often linked to the management quality of the process, it might therefore be used as a performance measure for the EMS itself. To do so, the natural variability of the system must first be quantified, as high process variability can also be due to the production of a wide range of products with varying emission burdens. This was the case at Company C, which manufactures a wide range of fine paper types resulting in a moderately variable IEI and highly variable TEPI. In this case the process emissions may have to be allocated to each product before being assessed.

The IEI does exclude a number of factors which should be included in the assessment. Firstly, the global issues covered by the BPEO assessment methodology, as well as some of those included in TEPI, are not covered by the IEI. There may be a role here for using some of the TEPI categories as separate tools with which to assess specific environmental impacts. For example, the IEI will only examine the health aspects of any VOCs released, whereas the ozone creation category might be used to optimise these releases within the local EQS limits for their contribution to photochemical ozone creation. It may be possible to include this category in the IEI in future (see section 12.3.1). Secondly, the IEI does not take into account the hazard and perception issues which the EMS ranking matrix is able to aggregate (see section 2.3.1). Future development of the IEI may be able to include major accident hazards as part of the assessment, but it will be less practicable to include qualitative social issues such as perception into the quantitative IEI. These issues can presently only be included in the frequency-severity technique used in the impact matrix.

Given these limitations it may be more appropriate to use the impact matrix to prioritise significant environmental effects, with the IEI being used as a second level assessment tool when local compliance with standards is given a high ranking and has been targeted for action.

12.2.3 Corporate Management.

Corporate management tools include an EMS similar to those used at a site level. However, the importance of certain issues at a corporate level may differ from those at a site level, even when compliance indices are used as part of a corporate environmental aspect matrix.

Comparison of the IEI and TEPI has shown that where compliance measures of site-specific indices are aggregated together the differences in environmental capacity at the sites will have a significant effect on the final outcome. Analysis of the indices at each of the participating companies showed that four out of seven could not support the interchangeability of the indices. The same was true for the combined assessment of the companies. This may throw into question the present use of site-specific compliance based techniques as part of an environmental management standard such as ISO14001 at a corporate level, and more importantly the piloting of such a system at a particular site before applying it, without using different measures of performance, to the organisation as a whole.

It may be more appropriate to use the TEPI or its constituent categories at a corporate level. However, the TEPI can only be used in this capacity to assess trends rather than making quantitative decisions. Due to the additive approach taken in the TEPI it responds to different drivers than the IEI even where site constraints are not influencing the IEI itself. Sensitivity analysis of the indices showed this at all of the sites, with the category average results giving a more appropriate response. The TEPI and its categories are therefore useful as a tool to monitor the environmental burden of an organisation, as it is able to aggregate a wide range of emissions emitted in different locations on a level plane.

The TEPI cannot be used to set corporate targets for improvement, as the potential to implement these changes will be different from site to site. This is due not only to the environmental circumstances present at a site, but also the present state of its technological development. To set a corporate target to reduce the waste heat burden by 25% across an organisation will be very easy to achieve for those sites that do not presently re-use waste heat, but may be physically impossible for those that have already installed such technology. Taking into consideration site circumstances the TEPI can be used to target planned improvements such that an overall improvement is gained at both the site and the organisational level. In doing so it would have to be accepted that major changes at a site may have a smaller effect on the total burden of the organisation when it is modelled in a unit world.

12.2.4 Site Reporting.

The reporting of site information takes place in a wide variety of formats. A separate report may be produced in addition to a encompassing corporate group report, where the site forms part of a larger organisation, or the site may have its information represented separately within the group report. The type of information also tends to vary from company to company and sector to sector (see section 1.5). The wide variety of stakeholders that read or use a company's environmental report all require different information. Employees will be interested in company projects, insurers in environmental liabilities and compliance.

The primary concerns all relate to the ability of the site to operate within the confines of the local capacity available, or to achieve compliance. Where information on environmental projects has been included this tends not to include any quantitative data. Such data tends only to be used for assessments made by outside bodies. To date the assessment of environmental performance by outside stakeholders, such as investment companies, has concentrated on compliance and the presence and quality of an environmental management standard. This type of approach has recently been taken by the BiE index of corporate environmental engagement (see BiE 1996). With many companies now going for ISO14001 - Environmental Management Systems - the issue of compliance on regulated releases will improve across the board, with most companies achieving 100% compliance.

Those companies operating a Quality Management System will be able to maintain compliance using the warning and action limits employed to determine when a product or material might be moving outside its specification. A similar approach can be taken to ensure that key emissions, which will have to be monitored as part of the consent, do not move outside the limits of the consent. With more and more companies attaining 100% compliance it will be more useful to monitor the extent to which a site has been using its allocated capacity, rather than whether it has been in compliance. Given the significance of site location on the IEI, and the inability of the TEPI to respond to the relevant primary drivers present at a site level, the IEI may an appropriate measurement tool. Where an EMS has shown actual emissions to have a high ranking, the IEI is able to show the extent of capacity used by a site and how this changes over time. This will allow a site to show continuous improvement, which forms part of the commitment to ISO14001.

There may be other issues, not presently covered by the IEI, which will need to be demonstrated using different indicators. Guidance in this area has recently been put forward by ISO in the form of ISO14030 (see ISO 1996b). In addition to this type of compliance based indicator, which illustrates how well a company is being managed at the local level, some stakeholders are now starting to take an interest in the actual mass emissions or environmental burden of a site. Many companies already publish emission data (see section 1.5), but have not yet put this into any form of environmental context. Given the generic nature of TEPI, it will be more appropriate where a stakeholder is interested in comparing a site or company on e level plane. To do this using site-specific indices would not be valid.

12.2.5 Corporate Reporting.

Corporate reports may contain information on a site-by-site basis or for the organisation as whole. As discussed for corporate management the TEPI can be a useful tool for providing additional information to the emission data presently provided by leading companies. The IEI has shown that the use of compliance or site-specific assessment tools, to compare sites and provide aggregate data at a corporate level, is invalid because of differences in site capacity. The TEPI will also permit organisations to present environmental burden data for their products or company in such a way that the actual emissions cannot be dis-aggregated to reveal commercially sensitive information. This may allow companies to provide more actual emission data than is presently the case, as a means of increasing sales or attracting attention.

12.2.6 Conclusion.

The areas of appropriate use for the IEI and TEPI can now be split over the Process Information Life Cycle as shown in Figure 12.1. The IEI, which is the most appropriate tool presently available for site application decisions, could also be usefully applied to site management and reporting, but not at the corporate level.

For corporate management and reporting, where data from a range of different sites and processes is being brought together, the TEPI is more appropriate for an overall view of environmental burden. The TEPI would also be useful in quantifying and reporting on the burden of a particular product or site but could not be used effectively for site management or site applications. The use of the two indices within these areas does have a number of limitations and scope for improvement. These are discussed in the next section.

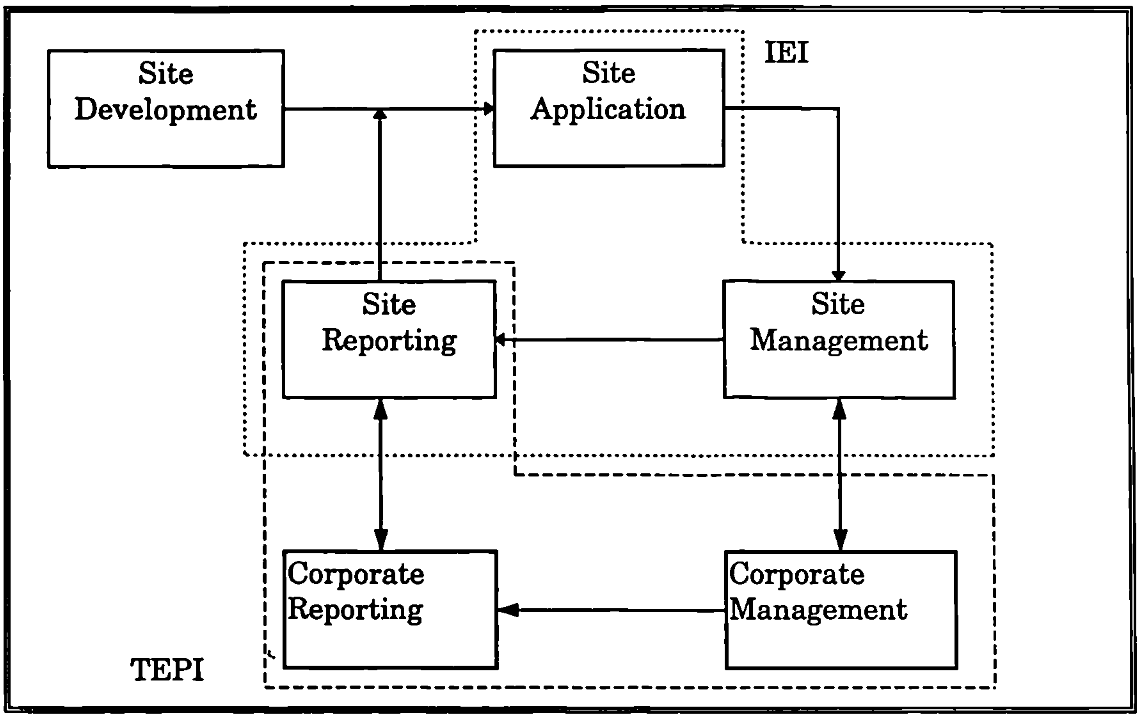


Figure 12.1 - The Appropriate Use of the IEI and TEPI for Process Assessment.

12.3 Limitations & Potential.

The two indices used in this project both have a number of limitations and areas of potential. Some of these have come to light by applying the indices at real industrial operations, with others being apparent from the start of the project. The additive approach taken with the potency categories of the TEPI is a good example of the latter.

12.3.1 The Integrated Environmental Index.

The IEI aggregates the environmental quotients calculated for each substance released in significant quantity to the environment from a process. The index is primarily used to select process options as part the BPEO assessment for IPC (see section 2.3.3 and EA 1997a). In doing so the index intends to make the best use of available environmental capacity, by ensuring that the process which uses the least overall amount of locally available capacity - i.e. has the lowest overall sum of the quotients - is used at a site. This methodology has received criticisms on three counts. Firstly, that the environmental quotients for releases to air, water and land cannot be added together and if this is to occur then some sort of weighting will need to be applied to represent the relative importance of these media. The IEI has been accused of attempting to add apples and pears (see ENDS 1995a), a criticism it shares with LCA. Secondly, that the basis for the Environmental Quality Standards and Environmental Action Limits used as part of the assessment is neither consistent nor based on standardised techniques or studies. Thirdly, that the index does not necessarily choose the option with the lowest mass emissions.

The first objection to the draft BPEO assessment methodology concerns the additive approach used to derive the IEI from the Environmental Quotients for each media. The basis for this approach was questioned (see ENDS 1995a) due to the different environmental effects that occur within each media. Some form of weighting might, therefore, be required before a IEI can be constructed. The use of weightings was derived from the LCA field where a similar problem exists for combining different environmental issues. As a result the published guidance for BPEO assessment (EA 1997a) has been changed to allow the use of the disaggregated EQs for each medium. The IEI does not need to be used as the central decision tool as long as this is justified as part of an application. In doing so the principle of integrated assessment, which forms the crux of IPC, has been abandoned.

The IEI is a simple integrated impact assessment tool which optimises the release of substances within the environmental capacity available at a site. This is done by comparison with an EQS or EAL for a substance to the relevant medium. This approach is a step forward from the mass emission based assessment methods such as the CIA methodology (see section 2.3.3 and CIA 1995a), which do not assess the effects of these releases on the local environment, to choose between process options. The IEI has been split down to the media air, water and land to facilitate dispersion modelling and derive the appropriate Process Contributions. The IEI could also be written as shown in Equation 12.1. The additive approach used to calculate the IEI from the EQs for each medium is also used to calculate the EQ for each medium using the EQs for each substance (see section 2.3.3). This approach would, therefore, also be invalid. The basis for this approach is centred on two problems, which have yet to be overcome. Firstly, the synergistic effects of multiple releases are not presently known and data on the local movement of substances from one media to another is not available, with the exception of air deposition to land.

Within the EQs for each medium it is presently not possible to calculate the combined impact of all the substances released.

Equation 12.1 - Alternative Form for Calculation of the IEI.

$$\mathrm{IEI} = \sum_{n}^{1} \mathrm{EQ}_{(s,m)},$$

For all substances, s = 1 ...n.
For all media, m = 1 ...n.

The EQS or EAL for a substance has usually been derived in the absence of any other pressures on the test organism. As a result the impact of a series of substances, all at 50% of their EQS or EAL may be well above the actual EQS for all the substances combined. These synergistic or additive affects have been shown to increase the toxicity of complex mixtures significantly (see, for example, Lefohn & Omrod 1984). As long as this limitation to the IEI is recognised the EQs for each media provide more valuable information than mass emissions alone. As more research is carried out on the synergistic effects of multiple releases, the EQSs within a medium might be adapted. Present focus in this area is on the use of whole effluent toxicity testing to set consents, as an alternative to concentration limits for key substances (EA 1996a).

Between the EQ for each medium in the IEI, the index is not able to take account of the multi-media fate of the substance released. The only exception to this is the deposition of air releases to land. The problem in trying to aggregate the EQs is not a social issue regarding the importance of one medium over the other. The present BPEO assessment methodology assumes - excepting air deposition to land - that all releases remain within the medium to which they have been released. The EQSs and EALs have been derived to ensure no long-term impact within each medium. However, in reality many substances will move from one medium to another, and may accumulate there over longer time periods than those for which the limits have been derived. Local data for multi-media modelling is presently not widely available, with limited data on the mobility, degradation and persistence of chemical substances. The approach has nevertheless been used as part of the waste hazard potentials calculated outside of the IEI. However, these are not site-specific assessments. Again, if the physical limitations to the IEI are accepted there should be no reason to disaggregate the index as it forms a pragmatic optimisation tool within the present constraints of scientific knowledge.

The second objection to the draft BPEO assessment methodology concerns the derivation of limit values as EQSs and EALs. These limit values have been derived using a wide range of tests and modified to include safety factors or politico-technological considerations - i.e. can the limits be reasonably achieved by present technology. As a result they do not represent a real-world no effect threshold, with limits both exceeding and conceding their actual environmental constraints.

The Environmental Quality Standards have been brought together from UK and EU legislation. These limits include a certain amount of political adjustment, while ensuring no average long-term detrimental impact. They provide an over-estimate of the amount of environmental capacity available. The Environmental Action Limits have been adjusted from Occupational Exposure Standards (OES) for the workplace, using a safety factor. As a result they provide an underestimate of the amount of environmental capacity available. This may vary, however, as the OESs were generally derived to safeguard human life only. In addition, the limited time over which the tests used to derive these limits are run mean that the long-term or cumulative effects of many substances are poorly represented.

The above issues not only raise concerns about the basis of the limits used, but also about the true environmental performance that compliance limits actually give. With sustainability becoming a major issue for industry, neither the EQS or EAL presently give a true measure of the limit to local sustainability (see Introduction). In the context of using the IEI within an EMS it may be advisable to calculate the compliant impact, using the EQSs and EALs, as well as an actual impact, using limits from NGOs and the scientific community, which more closely represent the true limit for a substance. Many of these limits, however, also underestimate the amount of environmental capacity available. Consequently, most measures of physical sustainability are spaced at different intervals around the true limit (see Figure 12.2).

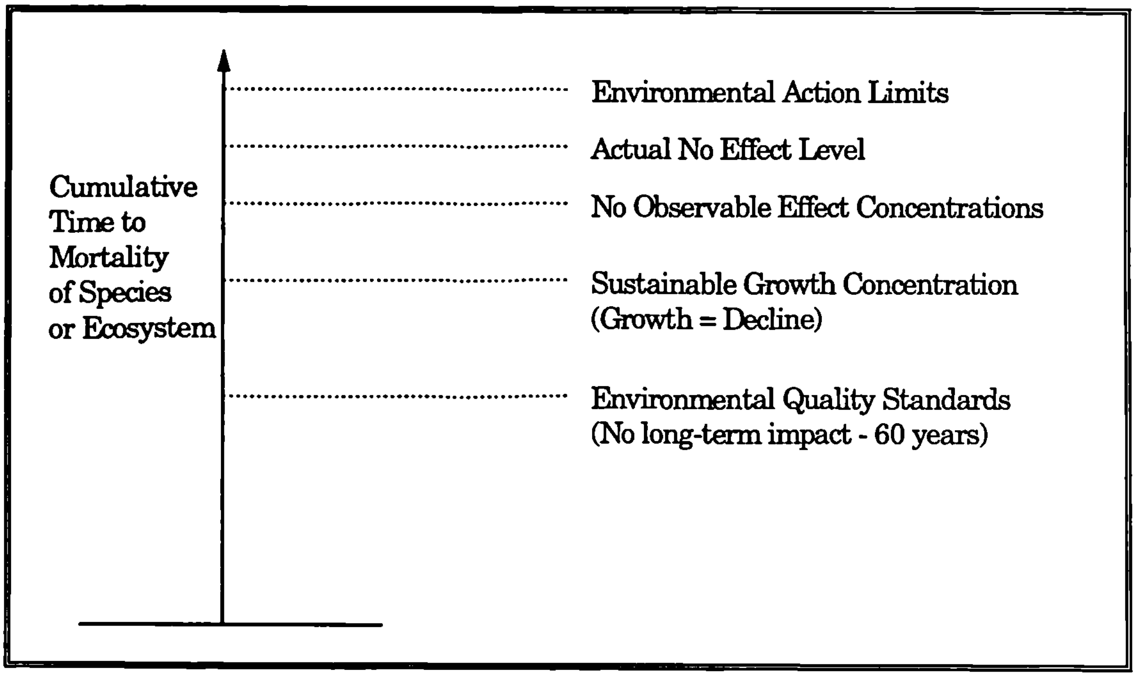


Figure 12.2 - Environmental Concentration Limits and Sustainability.

The environmental concentration limits which are presently closest to a sustainability limit for the release of substances to the local environment are No Observable Effect Concentrations (NOEC). These are also used to derive acceptable levels for humans, using safety factors to extrapolate from animals tests. These safety factors also take account of the threshold variability within the population. However, within the ecological environment this would not be necessary a sustainable threshold limit could be derived for a species or ecosystem.

For a given population of biota to be sustainable in the long-term it will be possible for that population to lose a certain percentage of its members from each generation and still remain viable. Present ecosystems already work on this basis through predation and herbivoral grazing. This factor might be included in setting sustainability thresholds for biological ecosystems not only from a toxicological point of view, but also from the perspective of how much land is required for a forest ecosystem to be sustainable, for example, and how much larger this must be if the forest ecosystem is to absorb a non-critical burden of acid deposition.

The third problem, identified during consultations on the BPEO assessment methodology, concerns a weakness in the IEI for releases to air. A case study comparing different options for a cement kiln showed that in some cases the IEI would rate an option with greater mass emissions above a low emission alternative (see ENDS 1995b). In response to this the use of mass emission based assessment techniques was proposed (Eduljee 1995, Eduljee & Turner 1996) and investigated (EA 1997b). The conceptual study carried out by WRC concluded that these techniques, which include LCA approaches, could not be used as an alternative site application tool. This thesis has confirmed that assertion with quantitative results.

Use of the IEI has shown that the problem stems not from the index itself, but from the nature of releases to air and the way in which these are modelled. As a result it is possible to influence the dispersion of releases without changing the process itself, or the quantity of substance released. The dispersion models used to predict the location with the maximum concentration are affected not only by the local meteorology, but also by the height of the stack, and the exit velocity and temperature of the release. These parameters can be adjusted for a process to give lower concentrations than a similar process with greater mass emissions. This is because, compared to releases to water, air releases are not confined to a catchment with a given flow curve within which to disperse. Releases to air can be dispersed over a wider area by increasing the stack height, or the exit temperature or velocity for a given release rate. By dispersing the same amount of material over a wider area, the concentration at the maximum location will drop. Within the air modelling framework, therefore, a number of technological factors can alter the results obtained, making them appear inconsistent when compared to mass releases. However, if the EQS or EAL for that substance is not exceeded this may not be a problem, given a physical limit to stack heights and the expense of wasting heat via the stack. The present planning guidelines for stack heights, however, are based on achieving enough dispersion for the substances released rather than reducing the total mass of material released. In the light of this there may be a case for examining the basis to these guidelines. There may also be a case for altering the parameters used to set the EQSs for releases to air and which are calculated by the air dispersion models. The USEPA ISCLT model is able to produce a map of concentration isobars for the area studied, which could be used to derive an integrated parameter for the 'area * concentration' of a given release. A second option might be to impose a physical limit, or air dispersion catchment, outside which the PC may not exceed 0.2% of the EQS or EAL for the substance released. These catchment areas would need to be placed around each stack, rather than being defined in a similar way to rivers, as emissions near the eastern border of a catchment would not be able to meet the 0.2% limit, given a predominately western airflow.

The above issue will be less simple to alter as it affects not only the IEI, but also the modelling techniques presently used. It also affects the planning process, much of which is presently outside the jurisdiction of the BPEO assessment methodology. It is this process related issue which has resulted in the very low IEI values obtained from companies A and B, both of which, in accordance with current planning policy, have stack heights which ensure appropriate dispersion of their emissions. Differences between the meteorology of the different companies will, nevertheless, still affect the results obtained.

A final limitation identified through application of the IEI, concerns the exclusion of a series of global and other environmental problems from the index. These factors, which have to be calculated as part of the BPEO assessment process, cannot be included directly in to the IEI. They include the global warming, photochemical ozone creation and waste hazard potential of substances released from a process. A number of additional environmental effects have been included without an assessment tool, such as odour and dioxin releases, for future development (HMIP 1995a).

These parameters cannot be included in the IEI as they do not result in environmental quotients. However, the global warming and photochemical ozone potentials have been used at an international level to allocate targets among the participants in environmental treaties. If these targets can be allocated amongst the regions of the UK they could then be used to calculate an environmental quotient using mass emission data on the relevant substances. If the priority for control of a substance is to be calculated in a similar way to other substances, then mass emission data must be available for each region. VOC releases would be priority for control, therefore, if the total release in an area (the equivalent to the

PEC) is greater that 80% of the area allocation, or if the company release is greater than 2% of the area allocation. The basis for including the quotients derived in this way, alongside those based on concentrations is less clear, and would probably need to be based on the present assumption of additivity and optimisation.

Assessment of the waste hazard potential of material sent for disposal has included a life cycle or policy issue into the assessment. As such this factor should not be used to influence a decision on whether a process is able to operate within the environmental capacity available at a given site. Such information could be used to provide product burden information, or inform policy decisions on the BPEO for a sector. These issues are discussed further in section 12.4.

The BPEO assessment methodology recently published by the Environment Agency represents a step in what is seen as an evolutionary process of method development. A number of potential changes have been proposed above, some of which could be incorporated immediately. Others will require further investigation. For example, if a multi-media approach is to be used in the IEI this may require a feasibility study. If the EQSs can be set to incorporate movement from one medium to another, this might be more practicable than having to carry out detailed studies around each IPC site. However, as many of the IPC processes will also be subject to CIMAH and have to assess the effects of accidental hazards on the environment IPC operators should be required to collect this data.

12.3.2 The Total Environmental Potency Index.

The TEPI aggregates a series of emissions by assigning them to a set of potency categories, which describe their contribution to an environmental problem. The extent of the problem is described by modelling the processes which facilitate the problem and stating the outcome relative to a reference substance. The TEPI has been very useful in showing the significant effect which site location can have on site-specific or compliance based indices. However, the index has a number of limitations which need to be addressed in the future. Firstly, as stated in section 3.3, an additive approach similar to the IEI was used to aggregate the potency categories. This was done in the absence of any known physical relationships between the categories. Use of the TEPI has shown that this approach may not be valid. The second and third limitations relate to the categories themselves. The categories chosen as part of the TEPI are the nearest generic set of potential impact indicators presently available. However, they are a combination of global, inter-regional and generic indicators, rather than a standardised set of generic potency categories all based on the same unit world. They are also presently incomplete.

The additive approach taken by the TEPI has meant that the index is dominated by the greenhouse effect and toxicity categories at all the companies taking part, where other releases such as acid gases and their contribution to the acidification are likely to have a similar or greater impact in a unit world. This is due not only to the large amounts of carbon dioxide and other global warming gases released, but also the very high potency factors used within the toxicity categories. In contrast the acidification category tends to combine low potency factors with relatively small releases. By using an additive approach the category totals, which represent the quantity of the reference substance released, have not been aggregated according to their relative impact on unit world. Consequently, the TEPI can be used to monitor trends in the environmental burden of a company, but cannot be used to assess changes quantitatively. However, the TEPI categories themselves can be used to do this on a problem by problem basis, with the average category change for a parameter, giving more representative results.

The problem of additivity has, in the past, been overcome within the LCA field by normalising the contribution of each potency category to the total burden for a given geographical area and weighting the resulting quotients using socio-economic data or expert review. However, many of the categories used, which represent the results from physical modelling exercises, do have physical relationships. The main problem in trying to tie these together lies in the level of impact of the categories used, and the spatial scale on which they are modelled.
The conceptual framework for life cycle impact assessment lays out a cause-effect chain for a given release (SETAC 1993a). The categories presently used on LCA represent a range of different impact stages for the release that they cover. Figure 12.3 gives the cause-effect chain for an emission of sulphur dioxide.

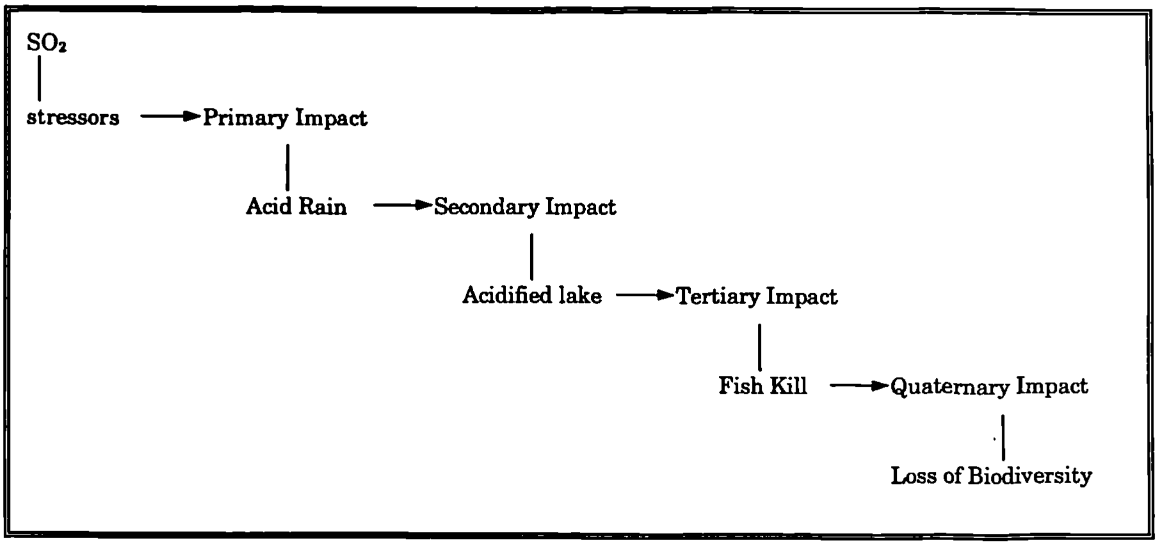


Figure 12.3 - The Cause-Effect Chain for Sulphur Dioxide and Acidification.

The acidification category used in the TEPI measures the potential for a release to contribute to acid rain, a secondary impact. This does not say whether a loss of biodiversity, the endpoint for most releases, will or has the potential to take place.

Each of the categories used in the TEPI represent the results of a modelling exercise for one of the impact stages along the cause-effect chain of the relevant releases. At present the TEPI categories represent a range of primary to quaternary impacts, as shown in Table 12.1. The categories also vary in scale or specificity. Some categories, such as the greenhouse effect and ozone depletion, have been modelled on a global scale, others on a west European scale, with the remainder representing generic chemical process models.

Each of the categories in Table 12.1 eventually contributes to a loss in biodiversity via different routes and interactions. Although many of the models used, for example to calculate the global warming potential of a substance, are very complicated they all have a physical relationship at some point along their cause-effect chain. Some of the potential links which might be expected are shown in Figure 12.4.

Table 12.1 - The Scale and Impact Levels of the TEPI Categories.

Category	Scale	Impact Level
GWP	Global	Secondary
ODP	Global	Secondary
HTP	Western Europe	Quaternary
AETP	Western Europe	Quaternary
TETP	Western Europe	Quaternary
POCP	Western Europe	Secondary
AP	Generic	Secondary
NP	Generic	Secondary
WH	Generic	Primary
LA	Generic	Primary/Quaternary

The TEPI categories are centred on the toxicity categories, to which they will eventually contribute either physically or chemically. The toxicity categories are all inter-linked, with no double counting of releases (see section 3.3). They are also the furthest down the cause-effect chain, although their spatial scale is presently based on western Europe rather than a unit or standard world. A number of the other categories are also inter-related, with all the categories having the potential to cause harm to human, terrestrial and aquatic ecosystems, as represented by the toxicity potentials.

The potency factors show that those gases contributing to the greenhouse effect also contribute to ozone depletion (see Guinee et al. 1992a). However, if a gas reacts to deplete ozone, it can no longer contribute to global warming. These interactions have presently not been quantified.

Releases of waste heat to air may contribute to the greenhouse effect, but may also have a local climatic effect. Releases to water have a toxicological effect on the aquatic environment, which is presently not included under the aquatic toxicity category.

The land area category has been chosen to represent the pressure of industrial and agricultural operations on the terrestrial environment. It also functions as a measure of the amount of land required to ensure that the terrestrial ecosystems, and the biotic resources they provide, are sustainable (see Introduction). As a result there is a two-way connection between this category and the toxicity categories. Firstly, if terrestrial toxicity potentials rise then the area of biotic resources available will fall. Secondly, if the area of land used by a company increases, then the amount of terrestrial ecosystem available falls. The link from the greenhouse effect relates only to the decrease in land area that might be expected from a global sea-level rise. The effects of global warming on vegetation and terrestrial ecosystems would feed through to the land area category via the toxicity categories.

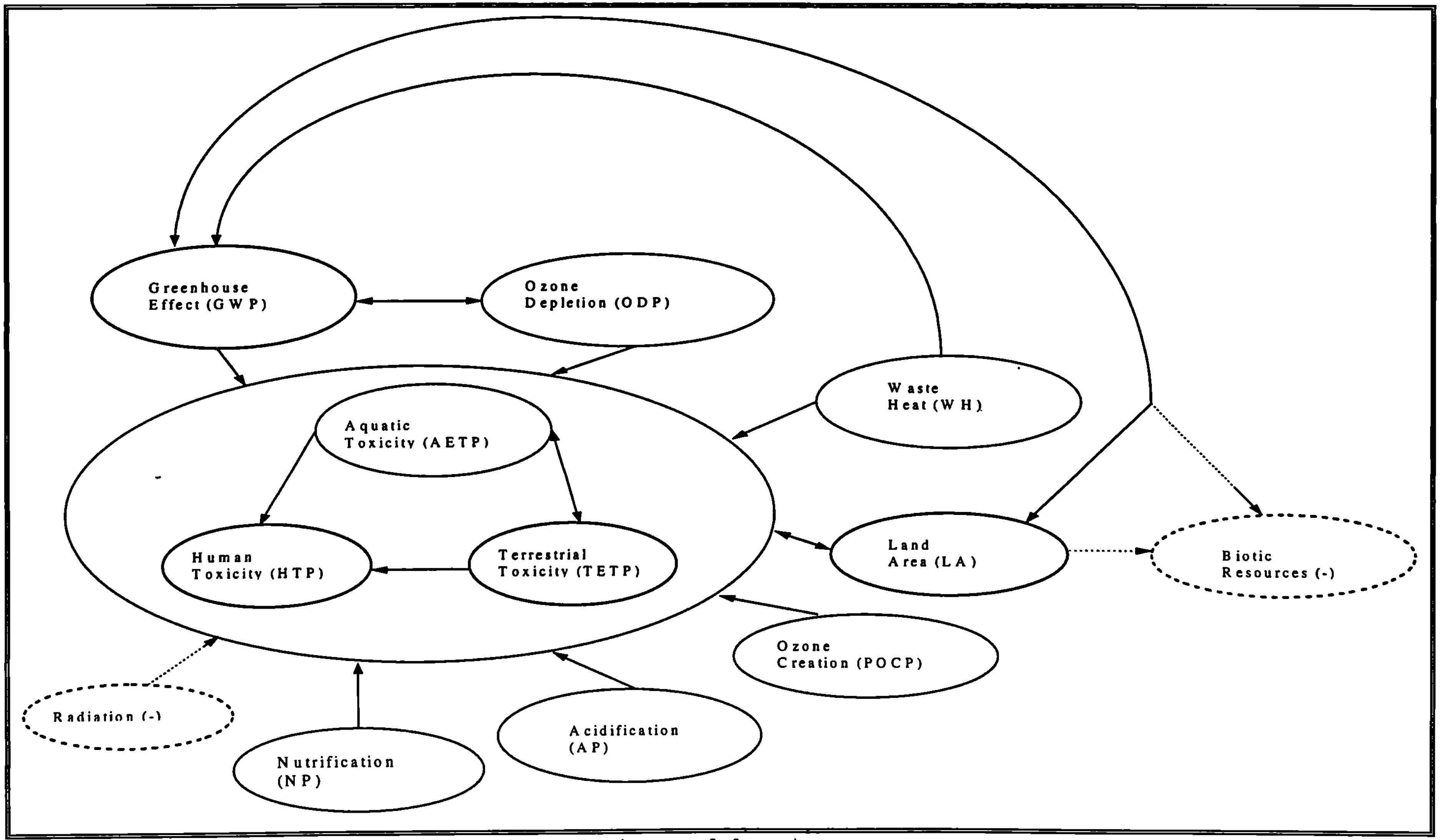


Figure 12.4 - Physical Links Between the TEPI Categories (present & future).

The remaining categories only have one-way links into the toxicity categories. The ozone created by VOCs in the photochemical ozone category is known to be toxic to both humans and plants. Releases of acid forming gases affect the toxicity categories directly and indirectly, via acid rain. They also make other pollutants more available, especially in soils. Finally, releases of nutrifying substances could be linked into the aquatic toxicity category.

Using the interactions in Figure 12.4 it may be possible to bring the primary and secondary order effect categories together into the models presently used to calculate the toxicity potentials. To do this the different spatial scales would have to be standardised, preferably as a generic unit world, rather than an area-specific environment. As the limit to loss of biodiversity, the ultimate end point for each category's effect chain, will vary from one area to another a generic unit world would need to be used.

The potency categories used in the TEPI are presently not complete with additional work now being carried out into releases of radioactive substances (see Solberg-Johansen et al. 1997), as well as biotic resources. These are shown as dotted lines in Figure 12.4. Unfortunately the radiation category has not been linked into the ecotoxicity categories, given that the modelling methods used are very similar. For the biotic resources the use of fund and flow resources is presently being studied. These fit better into the present framework than the area or animal numbers used previously (see Guinee et al. 1992a&b), and allow resources such as water to be included into the assessment. These concepts will fit into the land area categories presently used in TEPI, which is the controlling factor for many terrestrial biotic resources. The *flow* of biotic resources, for example as a sustainable harvest of timber, would be derived from a minimum area needed to sustain the fauna associated with it, or a *fund* resource of excess forested land.

The above relationships show that the potential is there to develop these generic indicators further and so get a better quantitative picture of society's true burden on the environment. These indicators can then be used to establish whether this burden can be sustained, direct effort to reduce the burden to such a level, and so ensure the sustainable development of future generations.

12.4 The Bigger Picture.

The Total Environmental Potency Index has been derived from the field of Life Cycle Assessment, which is itself presently also attempting to define its own areas of appropriate use. Similar to the questions raised concerning site and corporate environmental performance assessment, the LCA community is presently actively discussing the nature and basis of the impact assessment studies it uses. A second issue within the LCA community concerns that of data, with most LCAs presently using sector average data. This data is usually only collected for a site or company's principal suppliers, and their respective main suppliers, excluding a wide range of potentially significant impacts associated with the product under study. By comparing the problems and issues encountered within the high-level product or material studies, with those from the low-level process/site/company studies carried out as part of this project, some suggestions on the appropriate areas of use of data and assessment tools can be made. These issues can also be tied into some of the conflicts presently encountered in the UK by companies putting in IPC applications on the basis of BPEO, and the collection and presentation of data in national environmental reports.

12.4.1 Site-Specific vs Generic Inventory Data.

Within the LCA community, the inventory phase is now well developed. Data is readily available for those processes owned and operated by the company carrying out an LCA. However, where emission data for the production of a material used in the process needs to be collected externally, this is not the case. Such data is generally only available from industry associations as a sector average and will differ depending on the source used (see Ayres 1995) and the age of the original data.

The data is provided as a sector average so that specific member companies cannot be recognised and no distinction can be made between high and low emitters, often with old and new technologies respectively. By using this sector average data in an LCA the result may suggest a change from one material to another, where the actual emissions from the supplier of the high burden material may be much lower than the sector average given. Without assessing the range of emissions associated with a material supplier, a valid comparison cannot be guaranteed. In certain cases the distributions of the environmental burden from two materials may actually overlap, as shown in Figure 12.5. The figure shows the distribution of environmental burden from the manufacture of two materials, A and B, together with their respective sector averages, u. Using the distribution data an appropriate supplier could be chosen for the use of either material with the same environmental burden. However, using the sector average data material B would have been substituted by material A.

Comparison of emissions from the two paper mills taking part on the project showed wide differences between emissions to both air and water per tonne of

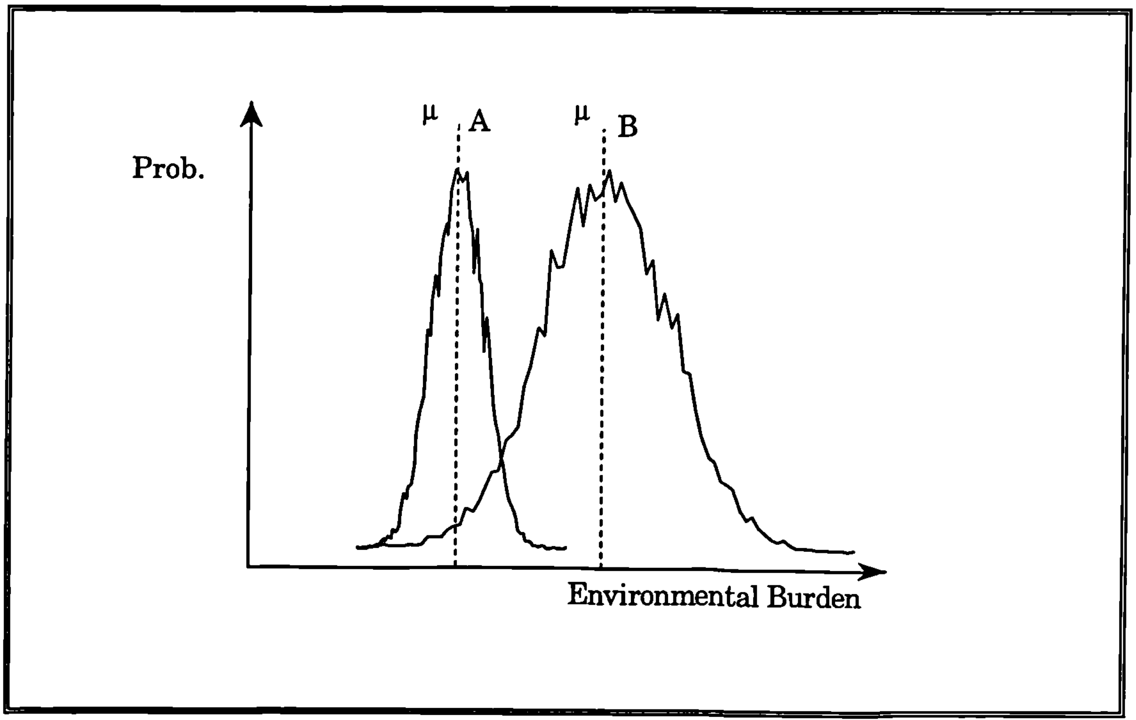


Figure 12.5 - Distributions of Environmental Burden from Sectors of two Materials.

paper produced, as well as between the mills and a range of LCA emission factors for the sector (see section 1.3). These findings support the results obtained by the Scott study on pulp suppliers (ENDS 1992, Fouhy 1993). The same was also true for the two power station staking part, both of which are fuelled by gas and fuel oil. At a company level there were also large differences between the emissions per unit of electricity generated and delivered by the UK average generation mix, Scottish Power and Scottish Hydro-Electric (see section 11.3.3).

These results suggest that this kind of data is important to the LCA field if valid material choices are to be made. Given the need for a separate corporate environmental assessment tool (see section 12.2), it may be appropriate to calculate the potential environmental effects of a process, product or company at this level of detail, rather than at the industry or sector level. The TEPI and its categories would then provide a standard method of aggregating and presenting emission data in a way that cannot be disaggregated into the commercially sensitive emissions which some operators wish to restrict. This may then allow industry association to provide a more valid picture of the range of environmental burdens originating from its members.

The large amount of variability between processes within a sector demonstrated by this project, together with other study results, presents a strong case for using this information to provide environmental performance data on the products or services sold to commercial clients. This already occurs at a company level by investors seeking to discriminate between companies on more than the presence of an EMS alone (see section 2.3.2). One company now also provides both emission and environmental burden data as part of its annual environmental report (see ICI 1997a&b), as discussed in section 1.5.

In order to provide continuous up-to-date product data, an environmental accounting system would need to be set up alongside the cost accounting system presently used by companies. The environmental accounting system would allocate the emissions from the manufacturing process to the product and combine these with the environmental burden data supplied on each of the materials and energy used by the processes and products. In doing so one of the major flaws and problems with Life Cycle Assessment to date would be solved. In order to set realistic boundaries for data collection in an LCA at present, only the primary materials used are assessed. This is done as their emission or burden data does not represent the life cycle burden of that material at the given point. Consequently, each supplier's supplier must also be assessed. In order to avoid analysing the whole world boundaries are placed around the primary material flows.

A recent study has shown that the implications of this assumption can have a significant effect on the results obtained (see Lave at al. 1995). However, if life cycle burden data was provided with each product this would remove the boundary and data collection problems and allow valid material/supplier assessments to be made. The use of such data as a commercial selling tool would provide a strong incentive for companies to set up such accounting systems. The results from the electricity generator study showed not only that the differences between generators were large, but also that the potential for these differences to affect the total burden of the companies using that electricity was also large, depending on the amount of energy generated by the site itself.

The potential effort required by companies wishing to implement such a system appear high. The project participants showed that the number of parameters covered by the IEI and TEPI that are readily accessible is low to moderate (see section 11.5.2), with the exception of Company E (see Figure 11.34 and Figure 11.35). However, their potential to estimate these emissions using mass balance techniques is very high, with a large amount of material input data now being highly or moderately accessible from the participants (see section 11.5.1). This accessibility is complemented by the large percentage of available product constituent data needed to estimate emissions (see section 11.5.3). If these techniques are to be used as a substitute to sampling, however, they need to be verified as representing the processes and emissions actually occurring at the given process or site.

12.4.2 Site-specific vs Generic Impact Assessment.

In contrast to the inventory stage of LCA, the impact assessment part of the methodology is still undergoing a great amount of discussion. A wide range of impact assessment methodologies are available, as discussed in section 2.2.2.2. The methodologies are either site-/area-specific or generic in nature, and arguments have been given for and against the use of both types (see section 2.2.3). The two groups of methods have been interpreted as a twin track of impact assessment by White et al. (1995), with no rationale for the appropriate use of the two approaches presently available within the LCA community. To help establish appropriate areas of use for LCA as a whole, however, the potential links with other assessment techniques, such as EIA and substance flow analysis, are being examined by LCANET, a network of LCA practitioners in Europe and Scandinavia (Wrisberg et al. 1997). In the absence of a framework the use of one technique over another is presently determined by the aim of the study. It is here, together with disparities in the quality and quantity of data used, that LCA has received the criticism that the desired outcome is predetermined this aim.

This study has highlighted the nature of the differences between the two approaches and established the need for site-specific tools at a process level, with generic level plane assessment tools used at a corporate or national policy level. For example, where two similar products are being compared, using the functional unit, this can only be valid if this is carried out on a level plane. Comparison of the IEI and TEPI has shown that site- or area-specific tools are significantly affected by the differences in environmental capacity present at the range of locations at which the stages of a product's life cycle are carried out. These differences are due to both the physical nature of the area where the site is located (e.g. the discharge of the river), and the number of other operations placing a burden on the area or catchment. The combination of these two will affect both the ambient concentrations and the consent limit in the area. Consequently, site- or area-specific assessment tools such as the IEI and the critical flow approach (see section 2.2.2.2), do not represent an independent measure of environmental performance for comparison on a level plane.

Much of the criticism levelled against the use of generic impact assessment methodologies is that the results are not always applicable at the site presently involved in the production stage which has been highlighted for improvement - i.e. the environmental capacity at the site cannot accommodate the changes or technology recommended. This factor was demonstrated by the effect of site location on the sensitivity of the IEI and TEPI, especially at Company D (see section 11.2.1). Here the IEI was dominated solely by BOD and copper releases (see Figure 11.10), where the category average for TEPI showed significant releases of sulphur dioxide and NO_x. At the other paper company (C), the IEI was affected more strongly by these two gases (see Figure 11.6). These differences between generic and site-specific capacity are to be expected and are not foreign to industry. The land area available for production is a good example of this. A company may decide to manufacture a different or new product and find that the production capacity or present set-up do not match the needs of the product. For example, a car manufacturer who designs a new model may find that the space requirements cannot be met at its present sites, and so must move to a location that can match these. Although a car might be designed around the production technologies presently available to manufacture it, a new car would not be designed around the physical constraints of the sites presently owned by the company. Similarly environmental capacity needs to be viewed as a resource which will vary from site to site and must be taken into account when planning purchases.

Generic impact assessment tools allow a company to minimise the overall burden of a product or material, whereas site-specific tools allow it to establish whether the chosen site can carry the environmental burden from the chosen process. At present, however, companies are under pressure not just to operate within the environmental capacity available at a site, but to reduce its use of that burden as far as is reasonably practicable - i.e. by applying BATNEEC/BPEO. This approach is used as environmental capacity is presently exploited as a common resource, within which additional space must be continually created to accommodate new developments. As a result the BATNEEC at a given site may actually cause the generic overall burden of a product to rise. This problem could be overcome by allowing companies to bid for environmental capacity. This has been carried out in the USA using the bubble concept. In Europe the approach has been adopted to permit companies under the Large Combustion Plant Directive to exchange and pass on quotas, with other applications being considered in the UK (see Moffat et al. 1991 for an example).

The above contradictions between the lowest overall environmental burden of a product or service, and the best environmental option for a given location, have also been encountered in trying to apply the BPEO assessment methodology within the UK over the past two years. A number of confrontations have occurred between companies and the regulators, the EA and SEPA, over their IPC applications, especially within the power sector. These confrontations are based on different perceptions of the BPEO for a process.

The Scottish Environment Protection Agency has recently objected to the construction of a gas-fired CCGT at Gartcosh in Lanarkshire by Scottish Power (ENDS 1997). The basis for this objection was that the power plant did not represent the most appropriate use of natural gas, a finite non-renewable resource. This despite CCGT's lower mass emissions and higher efficiency compared to conventional coal- or oil-fired plant. An earlier objection by Powergen against the requirement to install Flue Gas Desulphurisation equipment at its plant, are based on the exclusion of up- an down-stream effect from the IEI at present (ENDS 1996). The company argues that if limestone quarrying, transport and waste are included in the assessment the FGD has a net adverse environmental impact and is not the BPEO.

The above examples have taken a low level site-specific and high level sector-/product-specific approach to calculating the BPEO, where the IEI is intended to inform the BPEO for a site only. The sector-level arguments used by companies or regulators reflect the regulators' obligation to ensure the overall BPEO for a sector or region. This can sometimes conflict with the BPEO for a given process at a site, as occurred within the LCA field. The first issue on the efficient use of resources is a valid one. SEPA has argued that gas is more appropriately used to generate heat in domestic boilers (90% efficient), rather than generate electricity (55% efficient). The exclusion of CCGT from power generation, therefore, represents the BPEO for the energy sector, not for the Gartcosh site. This suggests the need for an energy policy for the sector, informed by high-level studies such as LCA which would exclude CCGT from the initial development plans for the Powergen site. Given a list of potential generation technologies, which represent the lowest overall environmental burden for the sector, the BPEO could then be determined for the site in question.

The above does not exclude the use of gas in all power plant, with high efficiencies also possible when gas is used in commercial CHP plant (ENDS 1997). This fact is presently being exploited by some power companies, who manage the CHP for industrial customers and export excess electricity to the grid (Scottish Hydro-Electric 1997). Despite the high level nature of the studies needed to inform the energy supply issue, which suggests the need for a specific policy by the regulators, the present setup of utility companies in the UK means that it could also become a company issue. With some utilities now owning both electricity and gas supply operations, considerable reductions could be made in the environmental burden per unit of energy supplied to customers. Given the differences in thermal efficiency between the direct supply of gas for domestic and commercial heat generation, as opposed to power generation, the provision of an integrated energy supply service could significantly reduce the burden per unit of electricity and heat by these utilities. This issue of thermal efficiency has been the driving force behind many of the joint venture commercial CHPs being constructed at present. The approach has yet to move into the domestic sector. With no known environmental assessments available on the above scenarios, the environmental accounting techniques using TEPI could be used to inform these decisions at both a company and government level.

The second confrontation, where high level issues were included in an index to inform a process application, demonstrates the same confusion between the BPEO for a sector and that for a site. Guidance is presently unclear whether the transport and waste disposal issues included by Powergen in its assessment should be assessed by the regulators or included as part of the BPEO assessment for a site. The exclusion of these factors from the IEI supports this. The up- and down-stream factors included in the Powergen study are important and will affect the final burden per unit of electricity supplied by the company. This data could then be used to inform clients and stakeholders. However, they should not be used to establish the BPEO for a process at a given site, as they do not affect the ability of the local environment to absorb direct emissions from it. The screening out of those options that do not represent the BPEO for a sector or product should take place prior to the site application, or should form part of an energy policy study to inform best practice guidance for the sector. Recognition of the above disparities between sector and site-specific assessments should permit the development of appropriate tools and systems by the regulators in the future. They suggest the need for decision-making at two different levels. The first, at a government level, to define a sector based strategy which provides a series of appropriate BPEO options for local consideration. The second, at a local level, to determine the site-specific BPEO from the sector BPEO options available - i.e. which option fits best into the local environmental circumstances present.

Use of the above techniques in making BPEO decisions at both a site-specific and national policy level, are all based on product or material comparisons per unit of function. This quantifies which product has a smaller burden, but does not tell us the total burden of the company or sector. Some restrictions presently imposed on industry, for example, via the Large Combustion Plant Directive, are not based on this type of comparison but on the total burden from a sector or country. With LCAs being used to develop more sustainable products, the total burden of the company has often been ignored. For example, if an organisation reduces the environmental burden of a product by 10%, but as a result increases its sales or market share by the same amount, the total burden of the organisation remains unchanged.

This introduces a final policy issue for the regulators, concerning the true sustainability of a nation. With industry operating in a wide range of environments a generic tool is needed to assess the environmental burden at a national level. Many nations are presently using the Pressure-State-Response approach to monitor this burden. However, no impact assessment presently takes place on the emission data collected. Future development of the generic assessment techniques such as TEPI should allow this to tale place. This data might then be linked into a measure of environmental capacity for a region or nation. Policy makers will then be able to use this data to decide which are the most appropriate industrial sectors to use that capacity, an issue which has so far not been tackled, and so ensure the optimum level of sustainable development.

12.5 The Future.

The above conclusions and perspectives allow an impact assessment framework to be put forward, which might be used to satisfy the aims of different studies (see Table 12.2). The framework differentiates between site-specific/compliance based and generic impact assessments for both products and processes or companies. The unit of assessment for a process has been called the functioning unit, in contrast to the functional unit for a product. The functioning unit represents the burden of the sum of the functional units for a company or sector. Each product and process section can be further split down into a specific data, quantifying the burden from a specific process, and generic data. The generic data quantifies the range of burdens from similar products or processes within the relevant sector. Not all the categories are likely to be of equal use at a company, product or national policy level, but they help to define which type of assessment and data should be used in which event, based on the significant differences between site and generic impact assessment studies and the variability in burden data within a given product/process range seen to date. Table 12.2 gives some of the performance data and examples of studies that might be carried out using the data from the categories given.

Table 12.2 - Provisional Data & Environmental Impact Assessment Framework.

Data *Impact Assessment*	*Process (Functioning Unit)*		*Product (Functional Unit)*	
	Specific	**Generic**	**Specific**	**Generic**
SPECIFIC	Company / process compliance data	Mean & range of process sector compliance or EMS performance for all products	Company product compliance data EMS performance data	Mean & range of product sector compliance EMS performance data
	BPEO EMS performance Process/site management & reporting	Benchmarking data source National sector compliance policy	Site management EMS performance Benchmarking	Benchmarking data source National product compliance policy
GENERIC	Company/process burden data	Mean & rang of process sector life cycle burden data	Company product burden data	Mean & range of product life cycle burden data
	Corporate/site environmental accounting & reporting Benchmarking	Bechmarking data source Input to national environmental accounts National burden policy Sector BPEO	Product information Product development Environmental accounting Benchmarking	Material assessment data source Benchmarking data source National burden policy Sector BPEO

Site-specific assessments are most likely to benefit the site's operations themselves. The process specific data forms the basis for all the other categories in this row. The category provides data on a specific company's compliance or EMS performance. The IEI is an example of a process- and site-specific assessment tool. The data from this category can be used to determine the BPEO for a site, and manage and report on its performance. The data can also be used to benchmark the site's compliance against other operators in its process sector.

The generic process category provides data on the range of compliance or EMS performance presently being achieved within a process sector. This data can either be used as a benchmarking data source, for comparison with site-specific performance data, or to inform national policy decisions on the compliance of industrial sectors. Incentive schemes could then be targeted at low compliance sectors, either to help them move to a more appropriate location or invest in cleaner technology.

Product-specific compliance data is obtained by allocating the process specific data to each of the products manufactured at a site. Some of the area-specific LCA techniques fall into this category. This data can be used for benchmarking against other products, and to assess the contribution of a specific product to the performance of a site. The data would not be valid for providing external product quality data, due to the effect of site differences.

The generic product category provides compliance data for all the manufacturers within a product sector. This can be used as a benchmarking data source for internal comparison, but not for external product quality comparisons or supplier assessment, which should be carried out on a level plane. The data might also be used to assess the compliance of different product sectors at a national policy level.

The generic impact assessments are more likely to be of use at a corporate level for product development and environmental accounting. The basis for all these impact assessments is the process-specific data category. This provides the environmental burden data for a specific company or site. It represents the basic data set required for an environmental accounting system. Ideally, the burden data would include all the prior process burdens for the life cycle of all its products up to this point. The data can be used for internal and external benchmarking, and to present burden data at both a site and corporate level. Any company in any location can be compared to another on a level plane using this data set.

The generic process category represents the mean and range burden data for all the processes within a sector. This type of data is presently provided by sector associations as emission averages. The data can be used as an internal and external benchmarking data source. The generic impact assessment techniques would allow companies to aggregate emissions in a standard way for input into sector association reports. The data can then also be used for national accounts on environmental burden or pressure. The data, which should represent the life cycle burden for the process sector can also be used to inform national policy, especially regarding the BPEO for a sector.

From the environmental accounts for a process or site, data can be derived for the product-specific category. This data can be used to provide product burden information to feed into the environmental accounting system of clients and agents. The data can be used to compare the product with others in the sector on a level plane and inform development decisions.

The generic product data category provides information on the range of burdens associated with all the products presently available within a sector. This data should represent the life cycle burden for the product to date. This type of data can be used to assess material substitution decisions and assess the potential variability in burden between suppliers. The category can also function as a benchmarking data source for internal and external comparison. The data can be used to assess the contribution of different process sectors to the national environmental burden and so inform the BPEO for those sectors.

If environmental accounting and reporting of this kind can be implemented at a company level it will provide a system that feeds well into the present reporting frameworks used at national and international level (see section 1.3), forming a step on the road to the quantification of sustainable development. The practicalities of achieving this type of system are less easy, however, despite the high amount of material based input data available in the companies studied.

The incentive for a company to provide this data must be stakeholder led. From the investor side this pressure is likely to increase in the future and presently represents the most likely force for collection and verification of such data. With an increase in the number of companies certified to ISO14001, clients and customers may start using more quantitative methods for choosing between materials and suppliers. Rather than looking for the presence or absence of an EMS standard, the presence of the standard should mean that high quality data is available for use in making a comparison and negotiating environmental specifications. Generic impact assessment tools such as TEPI will be able to inform these decisions. Final customer demand is likely to be smaller force, with many environmental products presently representing a niche market where the products command a premium.

A good example of an attempt to enlarge this market is the move by retailer Tesco to charge similar prices for organic and other vegetable produce. As a result customers can base their decision solely on environmental criteria. With cost being a primary driver, products with less overall burden are only likely to take hold if the prices are more comparable. This represents a step forward in the absence of environmental costing mechanisms which would make the use of both cost and burden data obsolete. Such a mechanism will not be possible until the environmental capacity can be more accurately quantified, at both a local and regional level. This is likely to take a number of generations. Once achieved it may be possible to derive an economic resource mechanism, whereby the price of environmental capacity increases towards infinity as it reaches its sustainable level. A number of studies on sustainability suggest that this level may have been exceeded, based on present growth rates in consumption and population (see Meadows et al. 1992). Consequently, if a sustainable level is to be achieved a number of step and gradual changes will need to be taken. The step changes will involve dramatic changes in technology, possibly even the cessation of certain industrial sectors, with continued improvement in material and energy efficiency within those that remain. Both site-specific and generic impact assessment tools will play a role in quantifying this level of sustainability.

In order to use the tools available more effectively, further research work will need to be carried out to improve the basis of generic indices such as the TEPI, as well as site-specific ones such as the IEI. As new effects of materials are discovered these will always have to be studied at a range of site-specific levels to determine the environmental variables which influence the effect of the material released. From these a generic impact assessment can then be derived and linked into the other impact categories present. Going on the present categories and their relationships, these links are likely to be centred on the toxicity categories. The primary areas of research needed to develop the two indices, that can be identified from this work, are given below.

12.6 Research Needs.

Both the indices studied can be improved in a number of ways (see section 12.3), some of which require further research.

(i) The potential effect of stack height, and exit velocity/temperature on the Environmental Quotients for air, and the IEI of process options needs to be studied. The need for and feasibility of an alternative air quality parameter for use in IPC applications can then be determined.

(ii) The potential significance of inter-media movement and accumulation of substances released to air and water, and applied to land, needs to be researched. This will enable decisions to be taken on:

(a) whether these factors need to be included in dispersion studies by IPC applicants; and

(b) whether the EQSs for substances need to be altered so that they correspond to a sustainable overall level of impact.

(iii) The basis for the determination of Environmental Quality Standards and Environmental Action Limits needs to be assessed to ensure that the limits used are consistent, and represent a sustainable level for the pollutants in the environment. Appropriate safety factors should be applied where necessary.

The safety factors should be set according to the precautionary principle, resulting in an underestimate of the amount of environmental capacity available. This will also allow the limits to be reduced, on the basis of further research, when pressure for environmental capacity becomes greater in the future rather than trying to reduce them once the effects are already occurring.

The approach would fit well into an assessment tool which views the sustainable carrying capacity of the earth as a resource. This area is not yet developed within the LCA field. The primary producers in industry are used to an evolving state of resource availability. Fossil fuel reserves have always been underestimated and increase as more exploration is carried out and technology improves. Similar investment would need to be made by those wishing to explore for additional environmental capacity, by sponsoring long-term effect projects to establish where safety factors can be reduced.

(iv) The physical relationships between the categories presently available within the LCA environmental theme approach need to be examined. From this their potential integration into the assessment model used for the toxicity potentials can be determined.

(v) Potency factors need to be developed for biotic resources. The factors must allow the resources provided by different ecosystems, and the pressure resulting from the destruction of these ecosystems, to be aggregated together.

(vi) The potential to measure positive as well as negative change within the potency categories needs to be investigated. At present this can only be done within the photochemical ozone category, where a number of pollutants have a negative effect on ozone creation. Within a biotic resources category, for example, such factors would allow the positive effects of those land-use changes that result in an increased diversity of fauna and flora to be included in the assessment.

(vii) If the potency factors are to be used as a set of environmental accounts, the factor of time will need to be included if valid comparisons are to be made. This will prove very difficult. The problem contains two disparate issues.

The first concerns the inclusion of end-of-life burden into the present environmental accounting system of a company. For processes such as nuclear power plant and landfill sites, the majority of emissions will occur after the site has fulfilled its useful life. A system for including these emissions into an annual account may need to be devised.

The second concerns the actual time at which the effect occurs compared to the time of release. This will be an issue both for the real world and a unit-world model. If annual accounts of environmental burden are to be used for comparison with data on the environmental capacity available then the two data sets will need to be time accurate. With some effects occurring a number of years after their release, the present and future burden data should be able to reflect this. Failure to do this would give a false impression of the environmental capacity available for use in the future.

(viii) At a site and sector level, the validity of mass balance derived data for use instead of sampling will need to be studied. Mass balances were used to substitute absent data in this project, but may be used to accurately predict emissions, for example, for processes with high volume effluents with low pollutant concentrations.

(ix) The significance of the differences between similar processes within the sectors of industry needs to be examined further. This will establish the potential use of the environmental burden for supplier selection and confirm the need for companies to collect and assess the potential environmental effect of their operations, rather than using sector average data.

12.7 Conclusion.

The IEI and TEPI have proved useful tools for demonstrating the significance of site location on compliance based indices and the importance of complete sector burden data in carrying out environmental assessments. As a result it has been possible to put forward a potential framework for carrying out environmental assessments at a range of levels within and outwith an organisation.

Both the IEI and TEPI will be able to play a future role in carrying out these assessments. This role will become more important as scientific progress allows the research needs identified to be incorporated into the indices, thus improving the accuracy with which environmental burden and eventually sustainability can be determined.

REFERENCES

ACCA. 1997. Guide to Best Practice in Energy & Environmental Reporting. The Chartered Association of Certified Accountants. London.

Admiralty. 1988. River Forth: Grangemouth to Stirling. Scotland - East Coast. Admiralty. Taunton.

Andersson, A., Ohlsson, T., Olsson, P. 1993. Life Cycle Assessment(LCA) of Food Products and Production Systems. Part I: LCA methodology, a literature review. SIK-Rapprt 193 Nr 599:1. SIK. Goteborg.

Andersson, K., Ohlsson, T., Olsson, P. 1994. Life Cycle Assessment(LCA) of Food Products and Production Systems. Trends in Food Science & Technology, Vol.5, No.5, pp134-138.

Aspinwall & Company. 1997. Procedure for Assessment of Environmental Aspects and Impacts. Aspinwall & Company. Singapore.

Assies, J. 1992a. LCA of Products: developments in LCA methodology. Presented at the Life Cycle Assessment workshop organised by the European Disposables and Nonwovens Association, 25th November 1992, Brussels.

Assies, J. 1992b. Towards a General Framework for Life Cycle Assessment. Presented at the CEFIC assessment workshop, 11 June 1992, Brussels.

Ayres. R.U. 1995. Life Cycle Analysis: A critique. Resources, Conservation and Recycling, No.14, pp199-223.

Bates, J. 1995. Full Fuel Cycle Atmospheric Emissions and Global Warming Impacts from UK Electricity Generation. ETSU-R-88. HMSO. London.

Benda, H., Narayan, R., Sticklen, J. 1993. Use of Expert Systems for Life Cycle Analysis. Automobile Life Cycle Tools and Recycling Technologies, SAE Special Publications, No.966, pp53-57.

BiE. 1996. The Index of Corporate Environmental Engagement: A Survey of the FTSE 100 Companies. Business in the Environment. London.

BMI, TME, NUB. 1994. PIA - Computer Program for Product Improvement Analysis. Institute of Applied Environmental Economics. 'S-Gravenhage.

Boubel, R.W., Fox, D.L., Turner, D.B., Stern, A.C. 1994. Fundamentals of Air Pollution. Academic Press. London.

Boustead, I. 1992. The Significance of Life Cycle Analysis. Life Cycle Analysis and Eco-Assessment in the Oil Industry, 26th November 1992, London.

British Gas. 1994. Range And Typical Composition Of Natural Gas Being Delivered Via The Gas Transportation System. Gas Business Engineering Data Sheet DAT33. British Gas. London.

BSI. 1994. Specifications for Environmental Management System BS 7750. British Standards Institute. London.

BUWAL. 1990. Methodik Für Oekobilanzen auf der Basis ökologisher Optimierung. Bumdesamt für Umwelt, Wald und Landschaft. Bern.

CEC, DG XI, DG XII, Eurostat. 1996. Environmental Indicators and Green Accounting. COM(94) 670 final. European Commission. Brussels.

CEFIC. 1993. Guidelines on Environmental Reporting for the European Chemical Industry. European Chemical Industry Council. Brussels.

Charlton, C., Howell, B. 1992. Life Cycle Assessment: A Tool for Solving Environmental Problems? European Environment, Vol.2, No.2, pp2-5.

CIA. 1995a. Environmental, Economic and BPEO Assessment principles for Integrated Pollution Control. Discussion Paper. Chemical Industries Association. London.

CIA. 1995b. The UK Indicators of Performance 1994. Chemical Industries Association. London.

Clarke, R.H. 1979. A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere. The First Report of a Working Group on Atmospheric Dispersion. NRPB-R91. HMSO. London.

Cohan, D., Gess, D. 1994. Integrated Life-Cycle Management. 1994 IEEE International Symposium on Electronics & the Environment, May 2-4, 1994, San Francisco.

Craighill, A.L., Powell, J.C. 1996. Lifecycle Assessment and Economic Evaluation of Recycling: A Case Study. Resources, Conservation and Recycling, Vol.17, pp75-96.

CSA. 1992a. PLUS 1107 User's Guide to Life Cycle Assessment: Conceptual LCA in Practice. Canadian Standards Association. Ontario.

CSA. 1992b. Z760-94 Life Cycle Assessment. Canadian Standards Association. Ontario.

Curran, M.A. 1993. Broad-Based Environmental Life Cycle Assessment. Environmental Science & Technology, Vol.27, No.3, pp430-436.

Dall'Acqua, S. 1994. Software Development of an LCA Program "Eco Proc 1.0". EMPA. St. Gallen.

Danish Steel Works. 1995. Green Accounts 1994. Danish Steel Works. Frederiksværk.

De Smet, B. 1992. Use and Relevance of LCA in Industry. EDANA workshop on Life Cycle Assessment, 25th November 1992, Brussels.

Derwent, R.G., Jenkin, M.E., Saunders, S.M. 1996. Photochemical Ozone Creation Potentials for a Large Number of Reactive Hydrocarbons under European Conditions. Atmospheric Environment, Vol.30, No.2, pp181-199.

DoE. 1995a. EC Eco-management and Auditing Scheme: A Participants Guide. Department of the Environment. London.

DoE. 1995b. Integrated Pollution Control: A practical guide. HMSO. London.

DoE. 1996. Digest of Environmental Protection and Water Statistics. HMSO. London

Dow Europe. 1995. Dow Europe - Continuing the Responsible Care Journey 1994/95. Dow Europe. Amsterdam.

DTTI, IISD, Sustainability. 1993. Coming Clean: Corporate Environmental reporting: Opening up for Sustainable Development. Sustainability. London.

Dyer, K.R. 1973. Estuaries: A Physical Introduction. Wiley. London.

EA. 1996a. The Application of Toxicity-Based Consents for the Regulatory Control of Wastewater Discharges. Environment Agency. Bristol.

EA. 1996b. The Environment of England and Wales. Environment Agency. Bristol.

EA. 1997a. Best Practicable Environmental Option Assessments for Integrated Pollution Control. Technical Guidance Note E1 (Environmental). The Stationery Office. London.

EA. 1997b. Environmental Protection Act 1990 Best Practical Environmental Option and Other Assessment Methods: Case Study Comparisons. R&D Technical Report P56. FWR. Marlow.

Eduljee, G.H. 1995. Practical Application of the BPEO Methodology. ERM. Oxford.

Eduljee, G.H, Turner, N.C. 1996. BPEO and LCA in Waste Management: A Comparison of Environmental Assessment Procedures. Journal of Waste Management & Resource Recovery, Vol.3, No.2, pp63-72.

EEA. 1995. Europe's Environment: The Dobris Assessment. European Environment Agency. Copenhagen.

Elkington, J., Hailes, J. 1993. The LCA Sourcebook: a European guide to life cycle assessment. Sustainability Ltd., SPOLD, BiE. London.

Emmerson, R.H.C., Morse, G.K., Lester, J.N., Edge, D.R. 1995. The Life Cycle Analysis of Small-Scale Sewage-Treatment Processes. J. CIWEM, Vol.9, pp317-325.

ENDS. 1992. Scott Ltd: Cleaning up the Paper Chain. The ENDS Report, No.214, pp16-19.

ENDS. 1994a. Controversial LCA study backs phosphate-based detergents. The ENDS Report, No.228, pp29-31.

ENDS. 1994b. The Elusive Consensus on LCA. The ENDS Report, No.231, pp20-22.

ENDS. 1995a. In search of the best practicable BPEO. The ENDS Report, No.249, pp22-25.

ENDS. 1995b. Questions persist over HMIP's BPEO assessment method. The ENDS Report, No.251, pp27-28.

ENDS. 1996. Questions over Powergen's "business as usual" BPEO case. The ENDS Report, No.256, pp8-9.

ENDS. 1997. SEPA questions use of gas in power generation. The ENDS Report, No.270, pp5-6.

Environmental Analysis Co-operative. 1996. Released Substances and Their Dispersion in the Environment. HMSO. London.

Eriksson, E., Blinge, M., Lovgren, G. 1996. Life Cycle Assessment of the Road Transport Sector. The Science of the Total Environment, No.189/190, pp69-76.

European Green Table. 1993. Environmental Performance Indicators in Industry: A system for corporate environmental performance evaluation. Draft Handbook. Touche Ross. London.

Fava, J.A., Page, A. 1992. Application of Product Life Cycle Assessment to Product Stewardship and Pollution Prevention Programs. Wat.Sci.Tech., Vol.26, No.1-2, pp275-287.

Fawer, M. 1994. Detergents: Life Cycle Inventory of Builder and Bleaching Systems. EMPA LCA group. St.Gallen.

Fecker, I. 1992. How to Calculate an Ecobalance? Report No.222. EMPA. St.Gallen.

Field, F.R., Isaacs, J.A., Clark, J.P. 1994. Life Cycle Analysis of Automobiles: A Critical Review of Methodologies. JOM, pp12-16.

Finnveden, G., Albertsson, A-C., Berendson J., Eroksson, E., Hoglund, L.O., Karlsson, S., Sundqvist, J-O. 1995. Solid Waste Treatment within the Framework of Life-Cycle Assessment. Journal of Cleaner Production, Vol.3, No.4, pp189-199.

Fouhy, K. 1993. Life Cycle Analysis Sets New Priorities. Chemical Engineering, Vol.100, No.7, pp30-34.

Fulton, A. 1992. LCA on Bioethanol: A Case Study. In: Phipps, J. Life Cycle Analysis and Eco-Assessment in the Oil Industry. Papers presented at a conference organised by the Institute of Petroleum Environment and Micribiology Committees, 26th November 1992, London.

Furuholt,E. 1995. Life Cycle Assessment of Gasoline and Diesel. Resources, Conservation and Recycling, Vol.14, pp251-263.

Gover, M.P., Collings, S.A., Hitchcock, G.S., Moon, D.P., Wilkins, G.T. 1996. Alternative Road Transport Fuels - A Preliminary Life-cycle Study for the UK. HMSO. London.

Gray, R., Bebbington, J., Walters, D. 1993. Accounting for the Environment. Chapman. London.

Guinee, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A. 1992a. Environmental Life Cycle Assessment of Products: Guide. Centre for Environmental Science. Leiden.

Guinee, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A. 1992b. Environmental Life Cycle Assessment of Products: Backgrounds. Centre for Environmental Science. Leiden.

Guinee, J., Heijungs, R., Van Oers, L., Van de Meent, D., Vermiere, T., Rikken, M. 1996. LCA Impact Assessment of Toxic Releases. Nr.1996/21. VROM. The Hague.

Hammond, A., Adriaanse, A., Rodenburg, E., Bryant, D., Woodward, R. 1994. Environmental Indicators: A systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development. World Resources Institute. Washington.

Heijungs, R. 1994. Life Cycle Impact Assessment: A Brief Survey with some Ideas on Radiation. Paper presented at the Technical Committee meeting on Development and use of environmental impact indicators for comparative risk assessment of different energy sources, IAEA headquarters, 3-6 May 1994., Vienna.

Hindle, P., White, P., Minion, K. 1993. Achieving Real Environmental Improvements Using Value:Impact Assessment. Long Range Planning, Vol.26, No.3, pp36-48.

HMIP. 1993. Guidelines on Discharge Stack Heights for Polluting Emissions. Technical Guidance Note D1 (Dispersion). HMSO. London.

HMIP. 1994. Environmental, Economic and BPEO Assessment Principles for Integrated Pollution Control. Consultation Document. HMIP. London.

HMIP. 1995a. Environmental, Economic and BPEO Assessment Principles for Integrated Pollution Control. Technical Guidance Note E1 (Environment). Volume 1: Principles and Procedure. Draft 2.0. Her Majesty's Inspectorate of Pollution. London.

HMIP. 1995b. Environmental, Economic and BPEO Assessment Principles for Integrated Pollution Control. Technical Guidance Note E1 (Environment). Volume III: Technical Data. Draft 2.0. HMIP. London.

HMIP. 1996. Validation of the UK-ADMS Dispersion Model and Assessment of its Performance Relative to R-91 using archived LIDAR Data. DoE/HMIP/RR/95/022. DoE. London.

Holden Meehan. 1997. An Independent Guide to Ethical and Green Investment Funds. Holden Meehan. London.

Holmark, D., Rikhardsson, P., Jorgensen, H.B. 1995. The Annual Environmental Report: Measuring and Reporting Environmental Performance. Price Waterhouse. Copenhagen.

Hope, C., Parker, J., Peake, S. 1992. A Pilot Environmental Index for the UK in the 1980s. Energy Policy, April, pp335-343.

Hope, C., Parker, J. 1995. Environmental Indices for France, Italy and the UK. European Environment, Vol.5, No.1, pp13-19.

Hunt, R.G. 1995. LCA Considerations of Solid Waste Management Alternatives for Paper and Plastics. Resources, Conservation and Recycling, Vol.14, pp225-231.

ICI. 1997a. Safety, Health and Environmental Performance 1996. Imperial Chemical Industries. London.

ICI. 1997b. Environmental Burden: The ICI Approach. Imperial Chemical Industries. London.

Iman, R.L., Conover, W.J. 1989. Modern Business Statistics. Wiley. Chichester.

IPCC. 1994. Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios. Cambridge University Press. Cambridge.

ISO. 1996a. ISO 14001: Environmental Management System - Specification with guidance for use. International Standards Organisation. Geneva.

ISO. 1996b. ISO 14031: Environmental Performance Evaluation. Draft. ISO/TC207/SC4. International Standards Organisation. Geneva.

ISO. 1997. ISO 14040 - Life-Cycle Assessment: Principles and Guidelines. International Standards Organisation. Geneva.

Jarvis, J. Per Comm. 1996. Contour Map of Eden Estuary. University of St. Andrews. St. Andrews.

Johnson, C. 1993. A Life Cycle Assessment of Incinerating or Recycling Waste Paper. MSc. Thesis. ICL. London.

Karna, A., Engstrom. J., Kutinlahti, T. 1993. Life Cycle Analysis of Newsprint. Canadian Pulp and Paper Association 2nd Research Forum on Recycling, pp171-178.

Keoleian, G.A., Menerey, D. 1994. Sustainable Development by Design: review of life cycle design and related approaches. Air & Waste, Vol. 44, pp 645-668.

Klopffer, W., Rippen, G. 1992. Life Cycle Analysis and Ecological Balance: methodical approaches to assessment of environmental aspects of products. Environment International, Vol.18, pp55-61.

KPMG. 1995. UK Environmental Reporting Survey 1995. KPMG. London.

KPMG. 1996. UK Environmental Reporting Survey 1996. KPMG. London.

Kuta, C.C. 1992. What is Life Cycle Analysis. HAPPI, April, pp72-78.

Lave, L.B., Cobas-Flores, E., Hendrickson, C.T., McMichael F.C. 1995. Using Input-Output analysis to estimate Economy-wide Discharges. Environmental Science & Technology. Vol.29, No.9, pp420-426.

Lee, J.J., O'Callaghan, P.O., Allen, D. 1995. Critical Review of Life Cycle Analysis and Assessment Techniques and their Application to Commercial Activities. Resources, Conservation and Recycling, No.13, pp37-56.

Lefohn, A.S., Ormrod, D.P. 1984. A Review and Assessment of the Effects of Pollutant Mixtures on Vegetation: Research Recommendations. EPA600/3-84-033. USEPA. Corvallis.

Lewis, E.L. 1980. Practical Salinity Scale 1978. IEEE Ocean Engineering, January.

MacAlasdair, D.S. 1993. The Practical Application of Environmental Life Cycle Analysis. 1993 International Industrial Engineering Conference Proceedings. Institute of Industrial Engineers. Norcross.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W. 1972. The Limits to Growth. New American Library. New York.

Meadows, D.H., Meadows, D.L., Randers, J. 1992. Beyond the Limits: Global Collapse or a Sustainble Future. Earthscan. London.

Meteorological Office. 1995a. Long-term annual average meteorological data summary (STAR) for Leuchars. Meteorological Office. Bracknell.

Meteorological Office. 1995b. Long-term annual average meteorological data summary (STAR) for Prestwick. Meteorological Office. Bracknell.

Meteorological Office. 1995c. Long-term annual average meteorological data summary (STAR) for Turnhouse. Meteorological Office. Bracknell.

Miakisz, J. 1994. Measuring Environmental Performance at Niagara Mowhawk Power. Total Quality Environmental Management, Autimn, pp47-56.

Miner, R.A., Lucier, A.A. 1994. Consideration in Performing Life-Cycle Assessments on Forest Products. Environmental Toxicology and Chemistry, Vol.13, No.8, pp1375-1380.

Moffat, I., Hanley, N., Hallett, S. 1991. A Framework for Monitoring, Modelling and Managing Water Quality in the Forth Estuary, Scotland. Journal of Environmental Management, No.33, pp311-325.

Newman, O., Foster, A. 1993. European Environmental Statistics Handbook. Gale Research International. London.

NMPC. 1991. Report on the Feasibility and Value of Establishing an Environmental Performance Index. Niagara Mohawk Power Company. Syracuse.

Nordic Council of Ministers. 1992. Product Life Cycle Assessment: principles and methodology. Nord 1992:9. Nordic Council of Ministers. Copenhagen.

Nordic Council of Ministers. 1995a. LCA-NORDIC Technical Reports No 1-9. TemaNord 1995:502. Nordic Council of Ministers. Copenhagen.

Nordic Council of Ministers. 1995b. LCA-NORDIC Technical Reports No 10 and Special Reports No 1-2. TemaNord 1995:503. Nordic Council of Ministers. Copenhagen.

North Sea Task Force. 1993. North Sea Quality Status Report 1993. Oslo and Paris Commissions. International Council for the Exploration of the Sea. London.

NPI. 1997. NPI Global Care Investments Environmental Research Summary: Best in Class. NPI. London.

NRA. 1993. AMP 2 Document. National Rivers Authority. Bristol.

NRA. 1995. Calculation of River Needs Consents. NRA. Norwich.

OECD. 1991. Environmental Indicators - a preliminary set. Organisation for Economic Co-operation and Development. Paris.

OECD. 1994. Environmental Indicators. Organisation for Economic Co-operation and Development. Paris.

Ordnance Survey. 1976. Falkirk and West Lothian. Sheet 65. 1:50 000 Second Series. Ordnance Survey. Southampton.

Ordnance Survey. 1981. Stirling and the Trossachs. Sheet 57. 1:50 000 Landranger Series. Ordnance Survey. Southampton.

Ordnance Survey. 1987a. Fraserburgh and Peterhead. Sheet 30. 1:50 000 Landranger Series. Ordnance Survey. Southampton.

Ordnance Survey. 1987b. Perth to Alloa. Sheet 58. 1:50 000 Landranger Series. Ordnance Survey. Southampton.

Ordnance Survey. 1987c. St. Andrews and Kirkcaldy. Sheet 59. 1:50 000 Landranger Series. Ordnance Survey. Southampton.

Ordnance Survey. 1988. Glasgow. Sheet 64. 1:50 000 Landranger Series. Ordnance Survey. Southampton.

PERI. 1994. The Public Environmental Reporting Initiative (PERI) Guidelines. British Petroleum. London.

Pittinger, C.A., Sellers, J.S., Janzen, D.C., Koch, D.G., Rothgeb, T.M., Hunnicutt, M.L. 1993. Environmental Life Cycle Inventory of Detergent-Grade Surfactant Sourcing and Production. JAOCS, Vol.70, No.1, pp1-15.

Potter, N., Isalski, H. 1993. Environmental Optimisation - The ENVOP Technique. Environmental Proctection Bulletin, No.26, pp17-25.

Puckett, J.C., Stauss, R.L., Wilson, C. 1991. Cradle-to-Grave Material Management. 1991 Transactions of the American Association of Cost Engineers, pp436-444.

Richter, K. 1993. Life Cycle Analysis of Wood and Wooden Products. Berichte Nr.1060. UDI.

RIVM, VROM, WVC. 1994. Uniform System for the Evaluation of Substances (USES). Version 1.0. Ministry of Housing, Spatial Planning and Environment (VROM). The Hague.

Salamitou, J. 1991. The Environmental Index: an environmental management tool for Rhone-Poulenc. Integrated Environmental Management, Vol.4, pp7-9.

Scottish Hydro-Electric. 1997. Annual Environmental Report 1996/97. Scottish Hydro-Electric. Perth.

Scottish Hydro-Electric. 1995. Annual Environmental Report 1994/95. Scottish Hydro-Electric. Perth.

Scottish Nuclear. 1995. Environment 1994/95. Scottish Nuclear. East Kilbride.

Scottish Office. 1994. The Scottish Environment - statistics. No.4 1993. Government Statistical Service. Edinburgh.

Scottish Power. 1995. Environment Update: policy, achievements and targets. Scottish Power. Glasgow.

SEPA. 1995. Water Quality Monitoring System Data: Alloa, 1988-1995. Scottish Environment Protection Agency. Edinburgh

SEPA. 1996a. Flow Data for Rotten Calder Water. Scottish Environment Protection Agency. East Kilbride.

SEPA. 1996b. Flow Distribution Data for River Carron. Scottish Environment Protection Agency. Stirling.

SEPA. 1996c. Flow Duration Curves for the River Eden and Motray Water. Scottish Environment Protection Agency. Edinburgh.

SEPA. 1996d. Long Term Statistics: Allan Water. Scottish Environment Protection Agency. Edinburgh.

SEPA. 1996e. Long Term Statistics: Bannock Burn. Scottish Environment Protection Agency. Edinburgh.

SEPA. 1996f. Long Term Statistics: River Black Devon. Scottish Environment Protection Agency. Edinburgh.

SEPA. 1996g. Long Term Statistics: River Devon. Scottish Environment Protection Agency. Edinburgh.

SEPA. 1996h. Long Term Statistics: River Forth. Scottish Environment Protection Agency. Edinburgh.

SEPA. 1996i. Water Quality Data: River Eden. Scottish Environment Protection Agency. Perth.

SETAC. 1991. A Technical Framework for Life Cycle Assessments. Society of Environmental Toxicology and Chemistry. Washington.

SETAC. 1993a. A Conceptual Framwork for Life Cycle Impact Assessment. Society of Environmental Toxicology and Chemistry. Penascola.

SETAC. 1993b. Guidelines for LCA: A Code of Practice. Society of Environmental Toxicology and Chemistry. Pensacola.

SETAC-Europe. 1992. Life Cycle Assessment: Inventory, Classification, Valuation, Databases. Society of Environmental Toxicology and Chemistry - Europe. Brussels.

SFIA. 1995. Paper Recycling - how far can we go? Swedish Forest Industries Association. Stockholm.

Sherwin, T.J. 1989. Methods for Determining Pollutant Dispersion in Tidal Waters. UCES Rpt U89-5(I:2). Unit for Coastal and Estuarine Studies. Bangor.

Smith, I.M. 1987. Trace Elements from Coal Combustion. IEA Coal Research. London.

Solberg-Johansen, B., Clift, R., Jeapes, A. 1997. Irradiating the Environment - Radiological Impact in Life Cycle Assessment. The International Journal of Life Cycle Assessment, Special Issue, February, In Press.

Sorensen, B. 1994. Life-Cycle Analysis of Renewable Energy Systems. Renewable Energy, Vol.5, Part 2, pp1270-1277.

Steen, B., Ryding, S-O. 1992. The EPS Enviro-Accounting Method: an application of environmental accounting principles for evaluation and valuation of environmental impact in product design. IVL. Stockholm.

Streatfield, C. 1993. Integrated Management (quality, health & safety and environmental systems). Integrated Environmental Management, No.23, pp11-13.

Sundberg, J., Wene, C-O. 1994. Integrated Modelling of Material Flows and Energy Systems(MIMES). International Journal of Energy Research, Vol.18, pp359-381.

Tipnis, V.A. 1994. Towards a Comprehensive Methodology for Competing on Ecology. 1994 IEEE International Symposium on Electronics & the Environment, May 2-4, 1994, San Francisco.

UN. 1982. Survey of Environment Statistics: Frameworks, approaches and statistical publications. United Nations. New York.

UN. 1983. Directory of Environment Statistics. United Nations. New York.

UN. 1987. Environment Statistics in Europe and North America: an experimental compendium. United Nations. New York.

UNECE. 1991. Protocol to the Convention on Long-range Transboundary air Pollution Concerning the Control of Emissions of Volatile Organic Compounds and their Transboundary Fluxes. United Nations Economic Commission for Europe. Geneva.

UNEP. 1994a. Company Environmental Reporting: A measure of the Progess of Business & Industry Towards Sustainable Development. United Nations Environment Programme. Paris.

UNEP. 1994b. Environmental Data Report 1993-94. Blackwell. Oxford.

Unilever. 1996. Environment Report: Our Worldwide Approach. Unilever. Port Sunlight.

Uni Storebrand. 1996. Storebrand Scudder Environmental Value Fund. Uni Storebrand. Oslo.

USEPA. 1992. User's Guide for the Industrial Source Complex ISC2 Dispersion Models. USEPA No.450/4-92-008A/B. USEPA. Research Triangle Park.

Vigon, B.W., Tolle, D.A., Cornaby, B.W., Latham, H.C., Harrison, C.L., Boguski, T.L., Hunt, R.G., Sellers, J.D. 1994. Life Cycle Assessment: inventory guidelines and principles. Lewis. London.

Virtanen, Y., Nilsson, S. 1993. Environmental Impacts of Waste Paper Recycling. IIASA.

Virtanen, Y., Miettinen, P., Juntila, V. 1995. Energy Issues in Life Cycle Assessment. COMETT II UETP-EEE, The Finnish Association of Graduate Engineers TEK, technical Research Centre of Finland VTT. Helsinki.

Wahl, P.R., Bersbach, P.L. 1991. TQM Applied Cradle to Grave. 45th Annual Quality Congress of the American Society for Quality Control, pp 666-670.

Walker, D.S., Galbraith, R., Galbraith, J.M. 1985. Survey of Nitrogen Oxides, Carbon Monoxide and Hydrocarbon Emissions from Industrial And Commercial Boilers in Scotland. Warren Spring Laboratory/DTI. Stevenage.

Warn, A.E., Brew, J.S. 1980. Mass Balance. Water Research, Vol.14, pp1427-1434.

Warren, J.L., Weitz, K.A. 1994. Development of an Integrated Life-Cycle Cost Assessment Model. 1994 IEEE International Symposium on Electronics & the Environment, May 2-4, 1994, San Francisco.

Watson, J. Per Comm. 1995. Ash Analysis - Sampled 12th October 1995. Scottish Coal. Edinburgh.

Watson, N. 1987. The Last Mill on the Esk: 150 Years of Papermaking. Scottish Academic Press. Edinburgh.

WCED. 1987. Our Common Future. Oxford University Press. Oxford.

Webb, A.J., Metcalfe, A.P. 1987. Physical Aspects, Water Movements and Modelling Studies of the Forth Estuary, Scotland. Proceedings of the Royal Society of Edinburgh, 93B, pp 259-272.

Wegener Sleeswijk, A. 1993. Life Cycle Assessment of Wheat Fertilization: methodological aspects and results. Proceedings of the 1st European Invitational Expert Seminar on Life Cycle Assessment of Food Products, 22-23 November 1993, Lyngby, Denmark.

Weidema, B-P., Christiansen, K. 1994. A Contribution to the Standardisation of Product Life-cycle Assessments. Integrated Environmental Management, Vol.28, pp18-22.

Wenzel, H., Hauschild, M.Z., Jorgensen, J., Alting, L. 1994. Environmental Tools in product Development. 1994 IEEE International Symposium on Electronics & the Environment, May 2-4, 1994, San Francisco.

White, P. 1995. Integrated Solid Waste Management: A Life Cycle Inventory. Blackie. London.

White, P., De Smet, B., Udo de Haes, H.A., Heijungs, R. 1995. LCA Back on Track: But is it One Track or Two. LCA News, Vol.5, No.3, pp2-4.

WICE. 1994. Environmental Reporting: A Manager's Guide. World Industry council for the Environment. Paris.

Wilson, B., Jones, B. 1994. The Phosphate Report: A life cycle study to evaluate the environmental impact of phosphates and zeolite A-PCA as alternative builders in UK laundry detergent formulations. Landbank Environmental Research and Consulting. London.

WMO. 1994. Scientific Assessment of Ozone Depletion: 1994. World Meteorological Organisation. Geneva.

Wrisberg, N., Udo de Haes, H.A., Clift, R., Frischknecht, R., Grisel, L., Hofstetter, P., Jensen, A.A., Lindfors, L.G., Schmidt-Bleek, F., Stiller, H. 1997. A Strategic Research Programme for Life Cycle Assessment. Final Document for the Concerted Action LCANET. CML. Leiden.

Young, S.B., Vanderburg, W.H. 1994. Applying Environmental Life Cycle Analysis to Materials. Journal Of Motoring, Vol.46, No.4, pp12-16.